WATER QUALITY CRITERIA FOR IMPLEMENTATION OF ANTIDEGRADATION WATER QUALITY STANDARDS

By

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I dedicate this work to the memory of my brother, Mark James Kenner, whose passion for excitement and perseverance for perfection provides me never ending inspiration.

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Chairperson: Dr. Wayne C. Huber
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Current water quality criteria have been established for protection of designated beneficial uses. These criteria do not represent ambient conditions nor incorporate natural water quality variability. Many water bodies have ambient water quality better than that established by the beneficial use criteria. For these water bodies the difference between the water quality necessary to maintain designated beneficial uses and ambient water quality is considered assimilative capacity. Historically, wasteload allocations of point source discharges have used assimilative capacity of receiving water bodies by allowing water quality to be lowered. The lower water quality is acceptable as long as designated beneficial use criteria are maintained. The focus of antidegradation policy is maintaining and protecting ambient water quality of high quality waters.

Implementation of antidegradation water quality standards requires numerical definition of ambient water quality. Inherently, representation and analysis of water quality data require statistical techniques. Standard statistical methods are not readily applicable to water quality data due to several characteristics: nonnormal data, missing values, seasonality, detection limits, and serial dependence. A formalized approach for statistical analysis of historical water quality data is established for representing ambient water quality.

Ambient water quality data are then used to establish water quality criteria based on criterion event definition. The criterion event definition consists of magnitude, duration and frequency of the water quality event of interest. Statistical representation incorporates natural variability of ambient water quality and can be effectively implemented for water quality management.

A formalized approach to data analysis is applied to the Suwannee River for development of antidegradation water quality criteria. The analysis does not focus on any specific percentile concentration and any percentile of interest can be identified and applied as a numerical criterion.

CHAPTER 1
INTRODUCTION

Background

Current water quality standards consist of three principal components: 1) designation of beneficial uses, 2) definition of water quality criteria necessary to maintain the designated beneficial uses, and 3) an antidegradation policy. The first two components, beneficial uses and water quality criteria, have played a major role in water quality management through control of point-source discharges. Most water quality criteria established for a specific designated beneficial use are constant numerical values that are not to be exceeded. Many water bodies have ambient water quality better than that established by the beneficial use criteria and are often referred to as high quality waters. For these water bodies the difference between the water quality necessary to maintain the designated beneficial use and the ambient water quality is considered assimilative capacity. Historically, wasteload allocations of point source discharges have used the assimilative capacity of receiving water bodies by allowing water quality to be lowered. The lower water quality is acceptable as long as the designated beneficial use

criteria are maintained. The focus of antidegradation policy is maintaining and protecting the ambient water quality of high quality waters.

Although a national antidegradation policy has existed since 1968 (USEPA, 1985b), actual implementation has been limited until recently. Public awareness for environmental concern has grown significantly in the past two decades. This concern has heightened the desires to maintain existing high quality waters. Subsequently, water quality management agencies are turning to antidegradation policy as the regulatory mechanism to protect and maintain ambient conditions of high quality waters.

Antidegradation Policy

Development of specific standards for unique or outstanding waters was recommended in the 1968 report of the National Technical Advisory Committee on Water Quality (Federal Water Pollution Control Asso., 1968). The basis of antidegradation policy was initially established in 1968 by the U.S. Department of the Interior and subsequently included in the U.S. Environmental Protection Agency's (USEPA) first water quality standards of 1975 (USEPA, 1985). This national antidegradation policy has remained mostly unchanged.

Apart from an initial objective to protect unique high-quality waters, antidegradation policy is formulated with regard to all surface water bodies. The national policy

consists of three components: 1) at a minimum the level of water quality necessary for existing uses shall be protected and maintained; 2) where water quality is better than that necessary to support the existing uses, it shall be protected and maintained unless allowing lower water quality is necessary to provide important economic and social development; and 3) high quality waters of outstanding national resource shall be maintained and protected (40 CFR Part 131, 1990). All states are required to adopt an antidegradation policy reflecting these three components and identifying how the policy will be implemented. A compilation of antidegradation criteria for several states (USEPA, 1988c) shows that antidegradation criteria are mostly narrative and essentially emulate the national policy.

The fundamental requirement for implementation of antidegradation policy is definition of numerical criteria representing ambient water quality with respect to a defined baseline time period. The numerical antidegradation criteria define 1) the ambient condition that must be maintained for Outstanding National Resource Waters (ONRW), 2) the ambient water quality baseline from which the amount of "allowable" degradation economically and socially acceptable can be defined, and 3) water quality level to be restored for water quality limited waters. Antidegradation water quality criteria are based on the ambient water quality of the

specific water body and can be referred to as water quality based criteria.

Terminology used for representing water quality can vary depending on regulatory definitions and interpretation. Within this document natural water quality refers to the water quality prior to any changes or impacts due to human influence. Ambient water quality refers to water quality conditions which incorporate changes in water quality due to previously permitted discharges with reference to the defined baseline time period. The baseline time period for establishing ambient conditions will vary from state to state depending on specific regulations.

Numerical Criteria

Development of numerical water quality criteria to represent ambient conditions can be presented in terms of four primary components: 1) quantity and characteristics of available water quality data, 2) preparation and analysis of the data to represent ambient conditions, 3) the specific numerical representation as criteria, and 4) application of the numerical criteria for water quality management.

Water Quality Data

Ideally water quality data should reflect the desired objectives of the analyses to be conducted. Objectives of the analyses include both long-term and short-term

characteristics. The sampling frequency controls the level at which short-term characteristics can be defined, while the sampling duration or period of record controls how well long-term characteristics can be defined.

Available water quality data are basically represented by either long-term data collected by a single agency or short-term data sets that have been collected by different agencies for special studies. The sampling frequency can vary over the period of record within a single data set and will vary between different data sets. Much of the available historical data has been collected without full consideration of the uses or objectives of the data analysis to be conducted. Short-term water quality monitoring efforts do not represent the long-term variability inherent in water quality. Past long-term monitoring efforts have lacked a clear definition of the desired information and statistical design necessary to make management decisions (Bell, 1989). The inadequacies of water quality information systems have been evaluated by several researchers (Ward et al., 1989). The two most often neglected considerations in the establishment of a monitoring program are a clear definition of the desired information and an understanding of the statistical nature of the analytical methods to be used in the analyses of the data. The ideal situation would be to obtain water quality data that have been designed with the objectives of the analysis taken into consideration. Unfortunately, this is not the case and much

of the available data have deficiencies with respect to the various analyses that must be conducted.

The lack of "quality" data often results in limited use of existing historical data or selection of study sites with adequate data for analysis. Water quality studies for evaluation of trends require consistent long-term records. Ten years of continuous monthly samples are recommened for evaluation of trends in water quality(Hirsch et al., 1984; Lettenmaier et al., 1991). Other common types of analyses performed on water quality data are development of a representative probability distribution and development of percentiles. With short data records it is often assumed that the data fit a lognormal distribution. The resulting distribution parameters do not incorporate long-term trends or cycles. Conversely, earlier data records are excluded from the analysis due to water quality trends. Crabtree et al. (1987) limited the period of record for development of water quality percentiles to three years to avoid long-term trends in the data. Representing receiving water quality as a lognormal distribution, Male and Soucie (1989) split their data visually to compare differences between earlier and current data records. When the current data were significantly different the early record was excluded from the analysis.

Many studies are conducted with fairly strict data requirements that result in elimination of much of the

available data. The available data are not included due to various reasons (not the same agency, variable sampling frequency, type of analytical test, consistency etc.). The data that do not meet the analysis requirements are excluded before the desired results are determined. The effect of including the poorer quality data in the actual analysis has not been reported.

The historical nature of the needed information precludes the development of a formalized monitoring network which takes into consideration the above concerns. The situation that confronts us is to gather available historical water quality data and, through statistical analysis, obtain as much information as possible to quantify the existing ambient water quality. Antidegradation inherently specifies a baseline time period around which the analysis must be conducted. This does not afford one the flexibility to select time periods which have the better data for analysis. Additionally, long-term data are necessary to identify trends and natural cycles in water quality. Representation of these characteristics of water quality requires use of as much data as are available. Subsequently, a primary objective of this research is to use as much of the available data as possible.

All available data at a specific location are considered by combining different agency data sets into one representative data set. It is evident that the data collected by different agencies can vary with regard to

sampling frequency, period of record, analytical techniques, sampling location, and minimum level of detection. These differences can result in different representations of the true underlying population. Therefore, combining of data sets collected by different agencies during different time periods must be done judiciously.

Data Analysis

Analysis of water quality data is formulated based on the desired information objectives and the characteristics of the available data. Some of the more common objectives include determining average conditions, long-term trends, percentiles, concentration-flow relationships, wasteload allocation and violations of water quality standards.

For establishing antidegradation water quality criteria three primary objectives are defined for the data analysis: 1) maximize the use of available data by combining multiple data sets at a single location into one representative data set, 2) evaluate and identify trends with respect to the baseline time period and remove trends that do not reflect ambient conditions of the baseline time period, and 3) numerically characterize ambient water quality variability due to seasonality and flow. As stated above the degree to which this can be done is based on the available data.

These objectives require several types of data analysis techniques. Statistical characterization of water quality has

become common practice for the management of water quality within all types of water bodies. Various methods are well documented in the literature for comparison of different data sets, evaluation of both monotonic and step trends, regression analysis of concentration and flow relationships, and defining seasonality. The need here is to combine these various methods together into a consistent formalized approach for characterizing ambient water quality.

Very little information is available regarding analysis and characterization of the data to be used to represent ambient water quality conditions for antidegradation. More emphasis has been placed on numerical representation as a criterion. Ward et al. (1988) established a data analysis protocol for evaluating short-term groundwater monitoring data. Although the objective of their analysis is exploratory relative to understanding the characteristics of the groundwater quality variable, the importance of a consistent data analysis approach is directly applicable for developing antidegradation water quality criteria. Breidt et al. (1991) go through a detailed data analysis prior to establishing antidegradation water quality standards for the Delaware Water Gap National Recreation Area. In their analysis they exclude data that indicate any possible trends and separate seasonal and non-seasonal data sets. This approach limits the analysis to data sets that meet the requirements of the statistical methods. When the only data available for a specific water

quality parameter indicate trend, no criteria are developed. Clearly a defined approach to data analysis is needed to provide consistent and repeatable analysis, uniformity for application to other locations within a basin, and yield the necessary information for water quality management.

Numerical Representation

Numerical definition of ambient water quality in terms of water quality criteria requires representation of natural cycles. Variability of water quality data is due to natural cycles within nature. Natural cycles that are readily apparent include seasonal variability of temperature and precipitation, and daily cycles of temperature and light. The natural variability of ambient water quality inherently leads to a probabalistic representation. A probabalistic representation also provides for the assessment of risks associated with various water quality management decisions.

The current trend for representation of ambient water quality is the use of percentiles. A percentile represents the percent of data measurements less than or equal to a specific concentration. Representation of ambient water quality using percentiles was established in European countries about 1980 with the policy of River Quality Objectives (Bernard, 1988) and is becoming more common in the United States. Typically a high percentile (95^{th}) is chosen as the criterion with the objective of protection against extreme

events. Extreme events are typically characterized by high concentrations for short durations. This type of event is not the only event than can result in changes in water quality. Nonpoint source discharges are typically due to landuse changes that take place over relatively long time periods, and the corresponding change in water quality is a gradual change in the average conditions. Establishment of numerical water quality criteria must recognize both types of events: 1) extreme events characterized by high concentrations and short durations, and 2) long-term events characterized by gradual changes in average conditions.

Recent work with regard to water quality based criteria for toxics uses three components for defining a specific criterion: 1) magnitude, 2) duration, and 3) frequency (USEPA, 1991a). The duration is the time period over which the parameter concentration (magnitude) is averaged and it is often referred to as the averaging period. The magnitude and duration are established based on laboratory toxicity tests. The magnitude is based on the concentration that produces a specific toxicity effect and the duration relates to the exposure time of the toxicity test. The frequency is established somewhat arbitrarily based on a qualitative allowable exceedence frequency for the defined event (EPA, 1991a). The concept of magnitude, duration and frequency is readily applicable to conventional water quality parameters based on ambient water quality.

A critical aspect of this type of representation is assigning a frequency (return period) to the criterion or event. The USEPA (1991a) makes reference to use of the concentration-duration curve of daily values to establish the frequency of the event. Theoretically, use of the concentration-duration curve to establish return period is incorrect (Searcy, 1959). The duration of the event must be defined and represented within each data point used in a subsequent frequency analysis. For example, to establish the return period for the average monthly concentration the frequency analysis must be conducted on data that represent average monthly values. This type of analysis parallels the development of intensity-duration-frequency curves for design rainfall. Selection of a duration should take into consideration the cause-effect relationship of the water quality parameter being evaluated. Toxic parameters typically have short response times, on the order of hours to days, whereas the response to increased concentrations of nutrients is likely to be on the order of months to years, depending on the level of increase in concentration. The specific duration that can be defined will also be based on the sampling frequency of the available data. This research examines the application of the magnitude-duration-frequency concept for representation of ambient water quality in combination with percentiles.

Application

Application of water quality criteria for management of water quality falls into two general categories: 1) wasteload allocation for establishing permit discharges and 2) evaluating and detecting future changes in water quality. Establishment of the numerical water quality criteria for antidegradation must take into consideration how the criteria are actually used if they are to be effective.

Implementation of water quality standards has historically been carried out through the National Pollution Discharge Elimination System (NPDES) permit program established in the 1972 Amendment to the Water Pollution Control Act (PL 92-500). Discharge permits are established in one of two ways: 1) treatment technology based effluent limits or 2) water quality based effluent limits. Treatment technology effluent limits are based on the "best practicable technology" (BPT) with reference to current practices. Water quality based effluent limits are established based on maintaining a specified level of water quality in the receiving water. When effluent limits based on BPT do not meet the desired receiving water quality, additional treatment measures are required. Implementation of antidegradation water quality standards clearly falls within the category of water quality based effluent limits. Current practice focuses on development of total maximum daily loads (TMDL) for specific parameters. The TMDL incorporates the waste load

allocation (WLA) for point source discharges and the load allocation (LA) for nonpoint source discharges. Several methods representing different levels of technical analysis are used for development of TMDLs (USEPA, 1991a; USEPA, 1991b). Although the objective of the TMDL process is to establish allowable parameter loadings, the receiving water quality is represented by an allowable concentration. An important consideration is which methods can best represent the variability of the water quality.

Monitoring future water quality provides information to detect changes in water quality and evaluate violations of water quality standards. Monitoring of future water quality is essential for evaluating the effect of implementing advanced treatment technology for point sources and best management practices for nonpoint sources initiated to either improve or maintain water quality. Effects on water quality due to point source discharges are readily evaluated by monitoring the effluent discharge and specific locations within the receiving water. However, effects of nonpoint source discharges rely primarily on monitoring the quality of the receiving water.

The ambient water quality representation must serve as a basis for changes in future water quality. Depending on the specific numerical representation used, various methods of comparison are available for detecting changes in water quality (trend analysis, changes in the mean, changes in the

standard deviation, and goodness of fit tests). Previous research has focused on the detection of exceedences of a single criterion by an extreme event (Hathhorn and Tung, 1988; Loftis and Ward, 1981; Male and Soucie, 1989; Warn and Matthews, 1984). Recognizing that the antidegradation criteria will incorporate both short-term (extreme event) and long-term (average event) criterion appropriate methods must be used for assessing each type of change in water quality.

Research Objectives and Organization

Two primary objectives are established for this research:

1) formalize several data analysis techniques into a consistent "data analysis protocol" that is generally applicable for establishing a water quality database representative of ambient conditions and

2) develop a numerical representation of the ambient water quality conditions that incorporates the natural variability of ambient water quality, and can be effectively implemented for water quality management.

The study area used for this research is the Suwannee River. A description of the study area, site specific antidegradation water quality standards, and characteristics of the available water quality data are presented in Chapter 2. Review of the appropriate literature is presented with each subsequent chapter topic. This is done to provide better continuity within the dissertation. Data analysis techniques

and a formalized approach to establishing an ambient water quality database are presented in Chapter 3. Numerical criteria based on ambient water quality are developed in Chapter 4 followed by an evaluation of appropriate methods for application of the established criteria in Chapter 5. Chapter 6 presents a brief summary of the research conducted, conclusions and directions for future research.

CHAPTER 2
STUDY AREA AND DATA

Study Area

Rationale

Under the Surface Water Improvement Act (SWIM), Sec. 373.451 FS, the Suwannee River Water Management District (District) is charged with the responsibility to restore and protect the quality of priority surface waters within the District boundaries. The significance of the Suwannee River is expressed by its designation as an Outstanding Florida Water (OFW) according to water quality standards of the State of Florida, Department of Environmental Regulation (FDER) (17-302.700, F.A.C.). This designation is in addition to the Class III usage classification for the Suwannee River (17-302.600 F.A.C.). Beyond the Class III water quality criteria, special protection for OFWs is provided through implementation of antidegradation permitting requirements (17-4.242 F.A.C.). The water quality criteria for implementing the antidegradation standard are referenced to the "existing ambient water quality" within the OFW. Subsequently, to implement antidegradation water quality standards for the Suwannee River ambient water quality must be defined.

The Suwannee River owes its popularity to its outstanding scenic beauty and undeveloped, unspoiled nature. Compared to other regions of Florida the Suwannee River Basin is relatively undeveloped except for one major phosphate mining operation. Recent pressure on new development in South Florida has generated increased development within the Suwannee basin. A heightened awareness of the potential increase in development within the Suwannee basin adds to the need for definition of ambient water quality for proper water quality management.

General Description

The following description is taken primarily from the Suwannee River Task Force, Report to Governor Bob Martinez (1989).

The Suwannee River originates in the Okefenokee Swamp in Georgia and flows south for 265 miles through Florida into the Gulf of Mexico (Figure 2-1). The entire drainage area of the Suwannee River is approximately 9,950 square miles, with about 4,230 square miles in north central Florida.

There are three principal tributaries to the Suwannee River. The Withlacoochee and Alapaha river basins lie mostly in Georgia, while the Santa Fe river basin is primarily in Florida. The river's flow is estimated to be approximately 1,550 cubic feet per second (cfs) at its entrance into Florida and 17,000 cfs when it empties into the Gulf of Mexico.

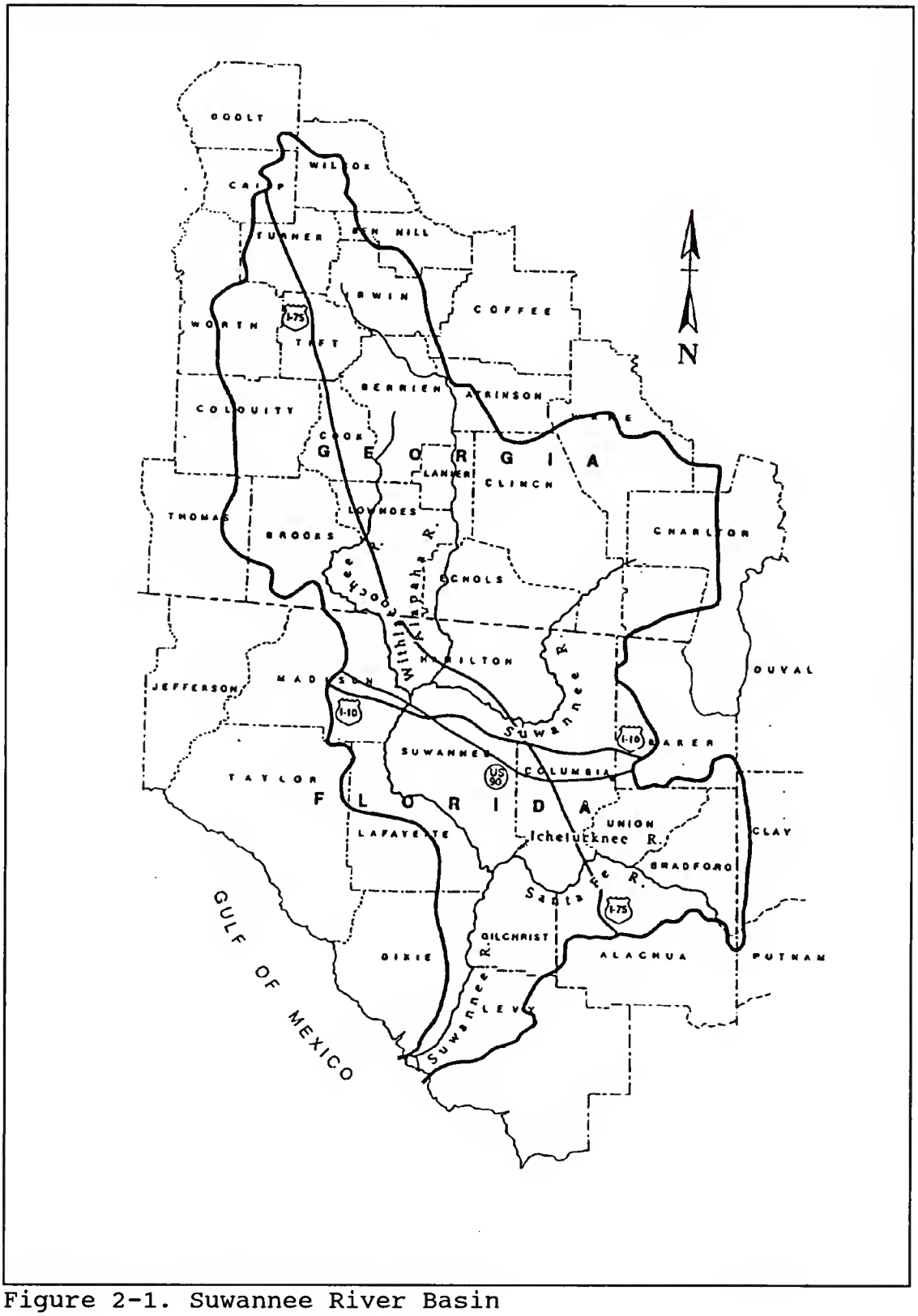

Figure 2-1. Suwannee River Basin

Unlike many rivers, the Suwannee's water quality is generally better downstream than upstream. The headwaters of the Suwannee River are characterized by dark and muddy flow, high in tannic and humic acids from decay of vegetation. The major tributaries and numerous springs in the lower reaches provide the Suwannee with higher quality water.

Regionalization

The Suwannee River within Florida can be divided into five regions based on a variety of features including floodplain morphology, geology, hydrology, water quality and biotic habitat.

Region I begins in the Okeefenokee Swamp and continues downstream about forty miles to White Springs. This river segment is characterized by numerous shoals and swift currents. Surrounding land uses are typically farmland, forest, and low-density residential development. The river flows over unconsolidated sands and the sand/clay/limestone of the Hawthorne formation. Water quality is dominated by surface runoff characterized by high color, low mineral content and slight acidity.

Region II covers the area from White Springs to the confluence of the Withlacoochee River, approximately 53 miles in length. This is a transitional area where the river crosses from the northern highland to the coastal lowland physiographic regions. Several springs enter the river

causing wide variations in water quality along this reach. The water quality will range from acidic to neutral pH, low to high conductivity, and high color to relatively clear. This reach is also influenced by phosphate mining discharges at Swift Creek.

Region III is 62 miles in length and includes the area from the confluence of the Withlacoochee to the Santa Fe River confluence. This reach also has many spring inflows. The river bed is mostly Ocala limestone. Water quality is now dominated by groundwater inflows and is generally clear to moderately colored, neutral pH, and higher conductivity.

Region IV is very similar to Region III and covers about 42 miles from the confluence of the Santa Fe River to just below Fowlers Bluff. The river bed lies on Ocala limestone and water quality continues to exhibit characteristics of groundwater inflows. Most of the drainage basin area is contributing to the river flow below the Santa Fe River and the flow volume is much higher and less variable than the upper region. The lower portion of this reach is influenced by moderate tidal activity.

Region V represents the river estuary. The estuary begins roughly between Fowlers Bluff and Gopher River. This region is relatively free of springs. The river bed is a mix of rock and sand, turning to sand and mud at the river mouth. The river is strongly influenced by tidal action and water

quality is becoming marine influenced with conductivities ranging from 300 to 26,000 umhos/cm.

Antidegradation Water Quality Standards

The current FDER antidegradation standard is set forth in Rules 17-302.300 F.A.C., 17-302.700 F.A.C., and 17-4.242 F.A.C. The three primary components of the standard are: 1) antidegradation policy (17-302.300), 2) special protection and designation of OFWs and Outstanding National Resource Waters (ONRW) (17-302.700), and 3) implementation of the policy through antidegradation permitting requirements (17-4.242). These three components are discussed in general and specific sections that apply directly to the objectives of this research are emphasized.

Antidegradation policy. Rule 17-302.300 (1)-(8) F.A.C. contains general antidegradation policy statements for all surface waters. Three key elements of the policy are summarized below.

1) The water quality necessary to protect existing beneficial uses (Class III) shall be maintained and discharge of wastes into Florida waters without treatment necessary to protect those uses is prohibited.

2) One of the most severe water quality problems is excessive nutrients (total nitrogen and total phosphorus) and the introduction of man-induced nutrients shall be limited.

3) If the proposed new or expanded discharge does not lower the quality below that necessary to maintain the beneficial use, a permit may be issued if the degradation that does occur is necessary or desirable and is clearly in the public interest.

This policy assures that the minimum water quality protection for all Florida waters is the water quality necessary to maintain the existing beneficial use classification. The Class III narrative criteria for nutrients (nitrogen and phosphorus), together with the emphasis on limiting introduction of excessive nutrients, is the basis for selection of total phosphorus and total nitrogen as parameters for the analysis.

Special protection OFW. Rule 17-302.700 (1)-(10) F.A.C. presents specific antidegradation policy for special protection of OFWs and ONRWs. Key elements of this policy are summarized below.

1) No degradation of water quality other than that allowed under the permitting process which is implemented pursuant to Section 17-4.242 F.A.C.

2) Designation of a Special Water (i.e. OFW) is based on finding that environmental, social and economic benefits provided by the ambient water quality conditions far outweigh costs to protect and maintain them.

3) For each OFW listed under Section 17-302.700(9) the baseline year for defining the "existing ambient" water quality is the year ending March 1, 1979.

This establishes the permitting process as the mechanism to implement the policy for protection of "Special Waters." More importantly it establishes February 1978 through February 1979 as the baseline time period for defining the existing ambient water quality.

Antidegradation permitting requirements. With regard to OFWs, the two major components of the permitting process are established in 17-4.242 (1) and (2) F.A.C. Section (1) prescribes the process required to determine whether a discharge is "necessary or desirable" and "clearly in the public interest." Section (2) establishes specific standards for OFWs. The initial foundation of the standard is provided in 1714.242(2)(a) which states:

> No Department permit or water quality certification shall be issued for any proposed activity or discharge within an Outstanding Florida Water, or which significantly degrades, either alone or in combination with other stationary installations, any Outstanding Florida Waters, unless the applicant affirmatively demonstrates that: . . . the proposed activity or discharge is clearly in the public interest.

The current FDER interpretation of this statement is that no direct discharges to any OFWs can degrade the existing ambient water quality (as specified in 17-4.242(2)(c)), and that indirect discharges cannot "significantly degrade" the existing ambient water quality. This implies that any direct discharges must be of the same quality as the OFWs. However,

for indirect discharges "significant" degradation is left undefined. Defining ambient water quality provides a definitive tool for use in assessing the significance of the degradation along with the environmental, social, and economic considerations.

Water quality degradation is measured as a change in water quality from the "existing ambient" water quality. The meaning of "existing ambient" water quality is defined in 17-4.242(2)(c) and states:

> The term existing ambient water quality shall mean (based on the best scientific information available) the better water quality of either (1) that which could reasonably be expected to have existed for the baseline year of an Outstanding Florida Water designation, or (2) that which existed during the year prior to the date of a permit application. It shall include daily, seasonal, and other cyclic fluctuations, taking into consideration the effects of allowable discharges for which Department permits were issued or applications for such permits were filed and complete on the effective date of designation.

The above definition for existing ambient water quality provides the impetus for evaluating the available surface water quality and quantity data in a probabilistic framework.

Data

Surface Water Quality Data

Water quality data are essential to development of ambient water quality criteria. A significant effort was made to identify and obtain all available surface water quality data for the Suwannee River. A primary source of water quality information is the USEPA water quality database

STORET. In addition to obtaining water quality data from the STORET data base, the following federal and state agencies were contacted:

United States Geological Survey (USGS),

United States Environmental Protection Agency (EPA)

United States Army Corps of Engineers (COE),

Suwannee River Water Management District (SRWMD),

Florida Department of Environmental Regulation (FDER),

Florida Department of Natural Resources (FDNR), and

Florida Game and Fresh Water Fish Commission (FGFWFC).

The established surface water quality data base for the Suwannee River represents data gathered by seven different agencies at twenty-four locations along the river. These locations consist of seventy-eight significant monitoring station data sets with periods of record ranging from two years up to thirty-six years and from twenty-three to one hundred fifty different parameters being measured. Eight of these monitoring locations were selected for inclusion in the analysis. These locations represent the temporal and spatial variability of water quality in the Suwannee River. Characteristics of the available water quality data at each location are presented in Table 2-1. This table presents information on the water quality data gathered by each agency at each location along the river. The location of each

Table 2-1. Suwannee River Water Quality Monitoring Stations

Group-ID	Agency	Station	Description	River Mile	Number of Parameters	Number of Samples	Period of Record
5 FOWLERS BLUFF	21FLGFWF	GFCNE0297	SUWANNEE RIVR AT FOWLERS BLUFF	14.5	29	4	Oct 88/Aug 88
	21FLA	21020022	SUWANNEE R AT FOWLERS BLUFF	14.5	57	29	Oct 81/Jun 86
	SRWMDT	SUW240C1	SUWANNEE RIVER AT FOWLER BLUFF	14.5	29	12	Feb 89/Jan 91
	SRWMDW	SUW241C1	SUWANNEE RIVER AT FOWLER BLUFF	14.5	23	26	Jan 82/Dec83
7 FANNING SPRINGS	SRWMDW	SUW160G1	SUWANNEE RIVER NEAR WILCOX	32.6	23	63	Jul 77/Dec 83
	1113S050	646300	SUWANNEE R AT US 19	32.6	17	14	Feb 66/Mar 66
	112WRD	02323500	SUWANNEE RIVER NEAR WILCOX, FLA.	32.6	130	132	Oct 60/Aug 88
	SRWMDT	SUW160C1	SUWANNEE RIVER NEAR WILCOX	32.6	29	18	Feb 89/Jan 91
	21FLA	21020031	SUWANNEE R @ US 19/98	32.6	116	165	May 70/Apr 90
	11FWS	058	SUWANNEE RIVER AT OLDTOWN	32.8	19	4	Oct 70/Oct 72
9 BRANFORD	SRWMDW	SUW140G1	SUWANNEE RIVER AT BRANFORD	74.9	23	62	Jul 77/Dec 83
	112WRD	02320500	SUWANNEE RIVER AT BRANFORD, FLA.	74.9	157	411	Jan 54/May 90
	1113S050	646910	SUWANNEE R AT 27 BRANFORD	74.9	13	14	Feb 66/Mar 66
	21FLA	21020035	SUWANNEE RIVER AT STATE ROAD 27	74.9	97	90	Sept 74/Jun 86
	SRWMDT	SUW140C1	SUWANNEE RIVER AT BRANFORD	74.9	29	18	Feb 89/Jan 91
	FGFWFC	BRANFORD	US 27 HWY BRDG OVER SUWANNEE SPINGS	74.9	29	3	Oct 68/Nov 70
	DERTLH	DERTLH009	SUWANNEE RIVER UPSTREAM OF HWY 27 BRIDGE	75	28	24	Jan 82/Dec 83
10 LURAVILLE	FGFWFC	PEACOCK SLOUGH	AT PEACOCK SLOUGH	94.6	29	3	Oct 68/Jun 69
	1113S050	647000	SUWANNEE R AT HWY 51	97.1	16	14	Feb 66/Mar 66
	SRWMDW	SUW130C1	SUWANNEE RIVER AT LURAVILLE FL	97.1	23	94	Jul 77/Jun 88
	112WRD	02320000	SUWANNEE RIVER AT LURAVILLE, FLA.	97.1	38	39	May 66/Feb 78
	SRWMDT	SUW130C1	SUWANNEE RIVER AT LURAVILLE FL	97.1	29	18	Feb 89/Jan 91
	DERTLH	DERTLH008	SUWANNEE RIVER UPSTREAM OF HWY 51 BRIDGE	97.1	28	24	Jan 82/Dec 83
	21FLA	21020034	SUWANNEE RIVER @ SR 51	97.1	89	48	Oct 73/Jun 86

Table 2-1. continued

Group-ID	Agency	Station	Description	River Mile	Number of Parameters	Number of Samples	Period of Record
14 ELLAVILLE	21FLA	21020014	SUWANNEE R ELLAVILLE US 90	126.6	60	31	Oct 77/Jun 86
	FGFWFC	ELLAVILLE	US 90 HWY BRDG OVER SUWANNEE SPRINGS	126.6	29	6	Oct 68/Oct 71
	SRWMDT	SUW100C1	SUWANNEE RIVER AT ELLAVILLE BELOW US 90	126.6	29	18	Feb 89/Jan 91
	DERTLH	DERTLH006	SUWANNEE RIVER DOWNSTREAM OF WITHLACOOCHEE	126.6	28	24	Jan 82/Dec 83
	1113S050	647095	SUWANNEE R ABOVE US 90 ELLAVILL	126.8	19	14	Mar 66/Jun 66
	SRWMDW	SUW100G1	SUWANNEE RIVER AT ELLAVILLE	126.8	23	94	Jul 77/Jun 88
	112WRD	02319500	SUWANNEE RIVER AT ELLAVILLE, FLA	126.8	56	15	May 66/May 70
16 SUWANNEE SPRINGS	112WRD	302346082561300	SUWANNEE RI NR NEW HWY 129 BRIDGE N	149.4	33	1	Nov 77
	112WRD	02315602	SUWANNEE RIVER NEAR SUWANNEE FLORID	149.6	1	1	Nov 77
	21FLA	21020015	SUWANNEE R AT FLA 129	149.6	55	26	Dec 81/Jun 86
	SRWMDW	SUW070G2	SUWANNEE RIVER AT HWY 51	149.6	23	1	Mar 79
	1113S050	647270	SUWANNEE R HWY 51 SW JASPER	149.6	23	14	Mar 66
	SRWMDT	SUW070C1	SUWANNEE RIVER AT SUW SPR AT OLD BRIDGE	149.6	29	18	Feb 89/Jan 91
	FGFWFC	SUWANNEE SPRGS	BELOW RAMP AT SUWANNEE SPRINGS	149.7	29	2	Feb 69/May 69
	SRWMDW	SUW070G1	SUWANNEE RIVER NEAR SUWANNEE SPRINGS	149.6	23	62	Jul 77/Dec 83
	112WRD	02315550	SUWANNEE RIVER AT SUWANNEE SPRINGS	149.6	99	127	Apr 56/Aug 88
18 WHITE SPRINGS	FGFWFC	WHITE SPRINGS	DAM AT STEPHEN FOSTER MEM PARK	168.7	29	4	Oct 68/Oct 71
	1113S050	647310	SUWANNEE R US 41 WHITE SPRINGS	171.1	21	14	Mar 66
	SRWMDW	SUW045G1	SUWANNEE RIVER AT WHITE SPRINGS	171.1	23	15	Apr 77/Sept 80
	21FLA	21020006	SUWANNEE RIVER @ US 41 & SR 136	171.1	113	121	Dec 72/Nov 85
	SRWMDW	SUW040G1	SUWANNEE RIVER AT WHITE SPRINGS	171.1	23	57	Jun 77/Dec 83
	21FLA	21020042	SUWANNEE R AT US #41	171.1	53	44	Jan 78/Sept 86

Table 2-1. continued

Group-ID	Agency	Station	Description	River Mile	Number of Parameters	Number of Samples	Period of Record
18 WHITE SPRINGS (cont)	112WRD	02315500	SUWANNEE RIVER AT WHITE SPRINGS, FL	171.1	128	115	May 66/Aug 88
	SRWMDT	SUW040C1	SUWANNEE RIVER AT WHITE SPR (US 41)	171.1	29	18	Feb 89/Jan 91
	SRWMDT	SUW030C1	SUWANNEE RIVER ABOVE WHITE SPRINGS & STP	171.2	29	18	Feb 89/Jan 91
22 SR 6	112WRD	02315000	SUWANNEE R NR BENTON FLA	195.7	96	93	Apr 56/Aug 88
	1113S050	647380	SUWANNEE R HWY 6 NE WHITE SPRIN	195.8	14	8	Mar 66
	SRWMDW	SUW010G1	SUWANNEE RIVER AT SR-6 OR NEAR BENTON	195.8	23	62	Jul 77/Dec 83
	SRWMDT	SUW010C1	SUWANNEE RIVER AT SR-6 OR NEAR BENTON FL	195.8	29	18	Feb 89/Jan 91

monitoring station is identified by the Group-ID. The Group-ID refers to a general location point along the river where several different agencies have gathered water quality data. The original source of the data is referenced by the agency code and the station is the specific name used by the agency for that monitoring location. The agency codes are defined below.

SRWMDW - Suwannee River Water Management District data collected prior to SWIM program and obtained from the District on floppy disk.

SRWMDT - Suwannee River Water Management District data collected under the SWIM program and obtained from the District on floppy disk.

21FLA - Florida Department of Environmental Regulation, Jacksonville data retrieved from STORET.

DERTLH - Florida Department of Environmental Regulation, Tallahassee; Suwannee River Limnology Study 1982-1983, data obtained from the Department on floppy disk.

112WRD - US Geological Survey data retrieved from STORET.

Additional information presented in Table 2-1 for each monitoring location includes approximate river miles measured in an upstream direction from the mouth of the Suwannee River at the Gulf of Mexico, number of parameters measured, number of samples collected over the period of record, and the actual period of record. Further discussion of this information follows.

Spatial distribution. Each location represents several agency monitoring stations that are located near a common reference point. At each location the different agency sampling points are within one mile of each other on the average. Figure 2-2 gives a visual representation of the eight locations selected for analysis. These locations provide a spatial representation with reference to the five regions that were described previously. These reaches are again defined in Table 2-2. The Ellaville location represents

Table 2-2. Reach Definitions for the Suwannee River

Reach	Description	River Mile
5	Upstream from the mouth to above Gopher Creek	0 to 10
4	Upstream from above Gopher Creek to mouth of Santa Fe River	10 to 65
3	Upstream from mouth of Santa Fe to mouth of Withlacoochee River	65 to 125
2	Upstream from mouth of Withlacoochee to White Springs	125 to 168
1	Upstream from White Springs to the State line	168 to 205

monitoring stations below the confluence of the Withlacoochee in reach 3. It should be noted that no monitoring locations within the estuary (reach 5) have been selected for analysis.

Period of record. The period of record reflects two characteristics: 1) the length of the time period over which the data were gathered, and 2) the specific time period the

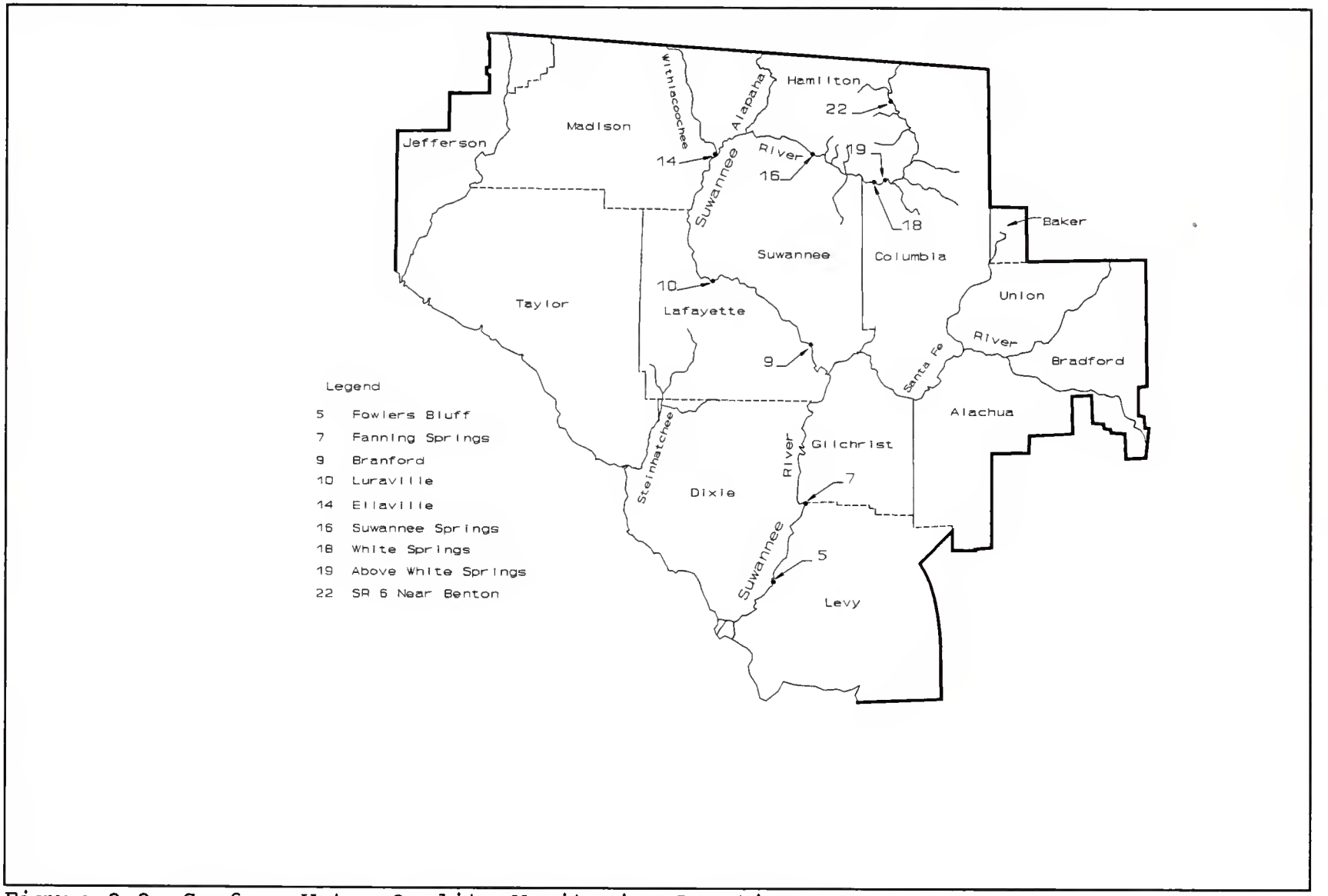

Figure 2-2. Surface Water Quality Monitoring Locations

data were collected. The available period of record will affect how well cycles and trends in water quality can be defined. The estimated long-term averages of cycles in water quality (i.e., seasonality) will improve as the period of record increases. Evaluation of cycles and trends is also affected by sampling frequency.

The evaluation of trends is necessary to determine how water quality has changed with respect to the baseline year ending March 1, 1979. Lettenmaier et al. (1991) recommend a 10 year period of record for analysis of trends. However, studies have been conducted on periods of record as short as two years (Hirsch et al. 1982). Ideally, the time frame from which the data were gathered would include a significant time period before and after the baseline year. The period of record for the various data sets range from two to thirty-six years.

The five USGS (112WRD) stations: Wilcox (Fanning Springs), Branford, Suwannee Springs, White Springs, and State Road 6 (SR6) near Benton, have long-term records ranging from twenty-four to thirty-six years covering the period from 1954 to 1990. These stations all incorporate the baseline year and provide the longest period of record of the available data.

The Jacksonville, FDER (21FLA) stations have varying periods of record. At Fanning Springs the period of record is about twenty years covering 1970-1990. At Branford, Luraville, Ellaville, and White Springs the starting date

varies from 1972 to 1979 and all end in 1986, with record lengths ranging from seven to fourteen years. These stations incorporate the baseline year. The Fowlers Bluff and Suwannee Springs stations all have five years of record covering the period 1981-1986.

The SRWMD has two data sets at each location representing data collected prior to SWIM legislation (SRWMDW) and data collected as part of the current SWIM program (SRWMDT). SRWMDW stations Fanning Springs, Branford, Suwannee Springs, White Springs and State Road 6 have six years of record covering the period 1977-1983; Fowlers Bluff has two years of record covering the period 1982-1983; and Luraville and Ellaville have ten years of record covering the period 1977-1988. The data obtained from the on going SWIM program (SRWMDT) cover the period 1989-1991 representing about two years of record.

The Tallahassee, FDER (DERTLH) stations were all established for a study of the limnology of the Suwannee River (FDER, 1985). These stations have two years of record covering the period 1982-1983.

The data gathered by the five agencies discussed above (112WRD, 21FLA, SRWMDW, SRWMDT, and DERTLH) represent the most significant data available for the project.

Sampling frequency. The sampling frequency represents the number of samples and time interval between the samples collected over the period of record. The time sampling

interval will dictate the time frame at which cycles can be determined. Typical cycles in water quality include short-term cycles reflecting daily variability, seasonal cycles (monthly, bi-monthly, quarterly) and long-term annual cycles. To characterize these cycles requires data collected within the time frame of the particular cycle being evaluated. For example daily cycles require sampling on an hourly basis and monthly cycles require sampling on a daily basis, whereas long-term seasonal cycles are based upon long-term averages of data collected within each season to be considered (monthly, bi-monthly or quarterly).

The average sampling interval for any specific agency and sampling location can be estimated by dividing the number of samples collected (Table 2-1) by the years of record. This average sampling frequency for each of the agencies can be misleading and should only be used as a rough estimate. For example, the average sampling frequency for 112WRD 02320500 (Branford) is approximately eleven samples per year indicating a monthly sampling frequency. However, the true sampling frequency is determined from an annual sampling frequency histogram. The sampling frequency histogram of specific conductance measurements at 112WRD 02320500 is shown in Figure 2-3 and indicates significant variability in sampling frequency over the period of record. From 1954 through 1957 two to three samples per month were collected, whereas over the most recent monitoring period (1984 to 1990) only

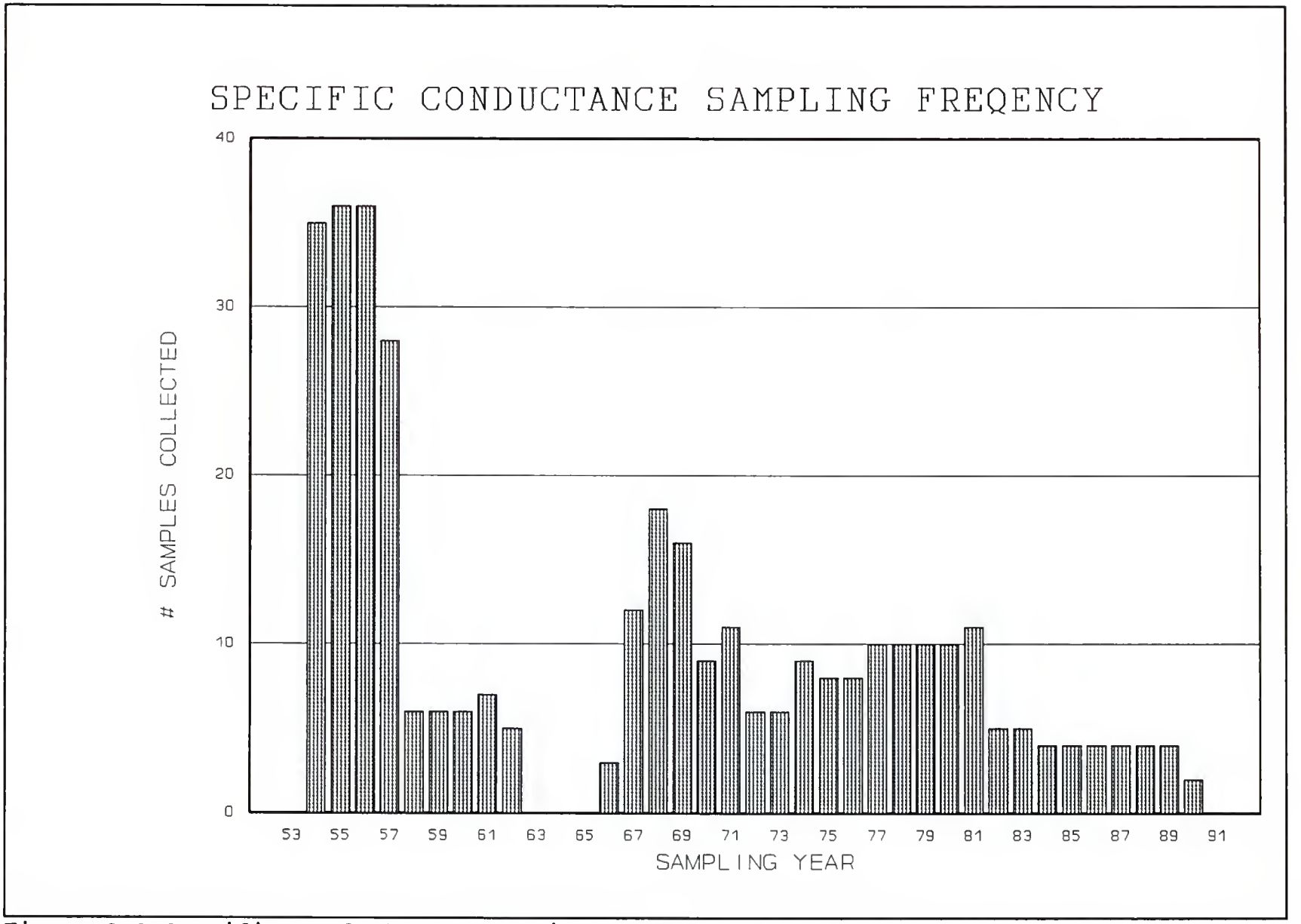

Figure 2-3 Specific Conductance Sampling Frequency at Branford

quarterly samples have been collected. Estimated long term averages or trends will tend to be biased toward the time period with a higher sampling frequency. Thus, the analyses must consider closely the variability of the sampling frequency over the period of record for each location and parameter.

Analytical methods. Specific analytical methods used to determine concentration of various water quality parameters can vary over the period of record and among different agencies.

Changes in analytical methods often lead to differences in accuracy and levels of detection between different time periods of the water quality data. The desired level of detection for a specific method can also vary based on the dilution or concentration used during preparation of the sample. Thus, methods used by different laboratories or at different times might be the same, but the level of detection can vary depending on the sample preparation. The level of detection can also change with improved methods and analytical equipment.

The difficulty of the method and experience of laboratory personnel can be a potential source of differences between data reported by different agencies. For example, specific conductance is a fairly straight forward analysis that has not varied significantly over time, whereas total phosphorus analysis can be done using various solvents for extraction of

the SRP fraction of total phosphorus. Extraction requires good laboratory procedure and experience of the lab personnel can influence the results.

In addition to laboratory procedures, collection of samples in the field can also be a source of variability. The type of sample collected (grab versus composite) and consistency of the specific location within the water body must be considered. With changes in personnel, water level, and accessibility the specific sample location can vary. This can affect results especially for monitoring locations just below tributaries or discharges as previously discussed.

From the discussion above potential for variability in the data due to differences and variability of analytical methods is quite evident. A detailed evaluation of differences between data analysis methods used by various agencies and for each water quality parameter would require a significant effort beyond the scope of this project. Even after a detailed evaluation of available information on the various analytical methods and laboratory procedures, often many questions still remain due to a lack of documentation. A major portion of water quality data were obtained from the STORET database. Within STORET each parameter code represents a specific analytical method. Parameter codes for STORET were used as a reference to verify analytical methods between agencies. Available information on analytical methods and sampling protocol of various agencies was obtained to gain an

understanding that will aid in knowledgeable interpretation of the data. In addition to gathering available information, personal communication with some of the agencies and laboratories was made.

Selection of parameters. Three parameters have been selected for use in developing the methodology to numerically define ambient water quality. The three parameters selected are specific conductance, total phosphorus, and total nitrogen. However, it should be noted that the methodology is developed for future application to other water quality parameters.

Specific conductance (SC) is a conservative parameter and provides consistent tracking for comparison between locations. Furthermore, it is monitored at most locations along the stream and has significant periods of record.

Total phosphorus (TP) and total nitrogen (TN) are used because problems associated with excessive amounts of these nutrients are well documented for various water bodies. Importance and concern for these two nutrients are the basis of one of the statements in the antidegradation policy (17-302.300 (3) F.A.C.). Additionally, the current Class III criteria for nutrients is narrative and numerical classification will provide a definitive basis for water quality management. FDER (1985) identified ortho-phosphorus as a better tracking parameter than total phosphorus. However, their study also indicated a significant positive correlation

exists between total phosphorus and ortho-phosphorus for the Suwannee River data they evaluated. Thus, analysis of TP will provide a general representation reflecting the characteristics of the sub-components of TP. TN values are not measured by all the agencies. However, TN values can be calculated by summing up total kjeldahl-N (TKN) and total nitrite-nitrate-N. Where the components of total nitrogen were available TN was calculated. In general TP and TN provide an overall assessment of the phosphorus and nitrogen components in the Suwannee River.

Flow Data

Flow data play an important role in the assessment of water quality. Flow data are necessary to evaluate possible relationships with concentration and for comparison of the long-term flow variability with the flow variability over the water quality period of record.

Available flow data for the project are taken from the USGS flow gaging stations within the basin. The main stem Suwannee River and tributary stations are summarized in Table 2-3. Figure 2-4 shows the location of the flow gaging stations within the basin.

Table 2-4 compares the period of record for flow data and water quality data. The water quality periods of record given in Table 2-4 represent the maximum combined period of record for all agencies at the referenced location.

Table 2-3. Summary of Flow Gaging Stations on the Suwannee River

STATION NAME (ID)	LATITUDE	LONGITUDE	PERIOD OF RECORD	YEARS OF RECORD	MISSING DATA
7. Suwannee River Near Wilcox (02323500)	29:35:22	082:56:12	1931, 1942-90	50	--
8. Suwannee River Near Bell (02323000)	29:47:28	082:55:28	1932-57	26	1932:Oct-May, 1957:Jan-Sept
9. Suwannee River at Branford (02320500)	29:57:20	082:55:40	1931-90	60	1931:Oct-Jun
10. Suwannee River at Luraville (023200000)	30:05:59	083:10:18	1927-38	12	1927:Oct-Jan, 1938:Jan-Sept
14. Suwannee River at Ellaville (02319500)	30:23:04	083:10:19	1927-90	64	1927:Oct-Jan
16. Suwannee River at Suwannee Springs (02315550)	30:23:34	082:56:00	1975-90	16	--
18. Suwannee River at White Springs (02315500)	30:19:32	082:44:18	1906-09, 1927-90	68	1906:Oct-May, 1909:Jan-Sept,1927:Oct-Jan
22. Suwannee River Near Benton (02315000)	30:30:30	082:41:50	1932-34, 1976-90	18	1932:Oct-Dec, 1934:Jul-Sept

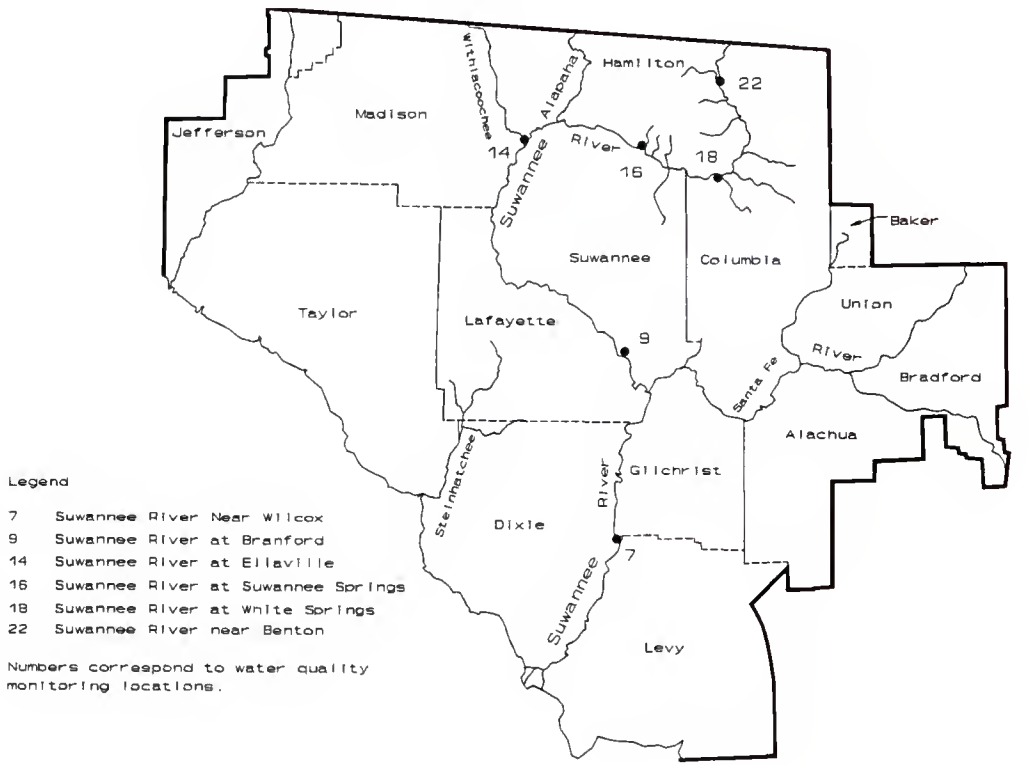

Figure 2-4. Suwannee River Flow Gaging Stations

Table 2-4. Comparison of Period of Record for Flow and Water Quality

Location	Flow Period of Record	Water Quality Period of Record
Wilcox (Fanning Springs)	1942 - 1990	1960 - 1991
Branford	1931 - 1990	1954 - 1991
Luraville	1927 - 1938	1966 - 1991
Ellaville	1927 - 1990	1966 - 1991
Suwannee Springs	1975 - 1990	1956 - 1991
White Springs	1927 - 1990	1966 - 1991
Benton (State Road 6)	1976 - 1990	1956 - 1991

Wilcox, Branford, Ellaville, and White Springs all have long-term flow records that overlap the quality monitoring period of record. The available flow record at Bell (Rock Bluff) does not overlap with the available water quality record. At Luraville the continuous flow record does not overlap the available water quality record. The USGS water quality period of record at Luraville covers the period 1966-1978 and instantaneous flow measurements are also recorded in the water quality database for this time period. The available water quality records for Suwannee Springs and Benton are longer than the available continuous flow records. For the time periods without continuous flow records, some instantaneous flow measurements are available at these locations from the USGS water quality data and reflect only the flow during the water quality monitoring period.

Flow data are recorded as daily averages for the continuous monitoring period of record. Thus, sampling frequency for flow data is daily and uniform throughout the continuous period of record except for missing periods. Instantaneous flow data recorded in the water quality database have a sampling frequency similar to the water quality data collected by the USGS (112WRD) for that specific location.

CHAPTER 3
DATA PREPARATION AND ANALYSIS

Literature Review

General

Sound water quality management decisions depend on competent characterization and interpretation of water quality data. The recognition of both natural water quality variability and sampling variability has led to the use of statistical techniques for characterization of water quality data. Two general objectives underlie all statistical analysis: 1) descriptive characterization in terms of specific parameters, and 2) use of sample parameters to infer or deduct something about the population (Gibbons, 1985). Recent research efforts have focused on the appropriate statistical methods for analysis of water quality data and have led to the emphasis of nonparametric methods (Hirsch et al., 1982; Hirsch and Slack, 1984; Lettenmaier, 1976; Montgomery et al., 1986; van Belle and Hughes, 1984; Ward et al. 1988). Parametric procedures make inference and tests of hypothesis that are based on parameter values of the underlying distribution. Traditional statistical inference is based on the assumption of normality. The Student's t-test and analysis of variance

(ANOVA) are examples of parametric techniques that assume the underlying population is normal. Nonparametric statistics make no assumptions as to the distribution of the sample population. Nonparametric implies a test for a hypothesis which is not a statement about the parameter(s) of the sample distribution. Nonparametric tests are formulated as a function of the order statistics or rank-order statistics of a random sample.

The collective order statistics of a random sample from a population with a continuous distribution are represented by the unique ordered arrangement such that $X_{(1)}$ is the smallest, $X_{(2)}$ is the second smallest, etc.; and $X_{(n)}$ is the largest of the random sample $X_1, X_2, \ldots, X_n$. $X_{(r)}$, for $1 \leq r \leq n$ is called the r^{th} order statistic. Rank-order statistics for a random sample are any set of constants which indicate the order of observations. Commonly the set of numbers used to establish the ranks are the first n positive integers. The rank of the r^{th} order statistic, $X_{(r)}$, is simply r and $r(X_{(r)})$ is called a rank statistic. The magnitude of any observation is only used to establish the rank. Thus, any statistical procedure based on rank-order statistics depends only on the relative magnitudes of the observations not on parameters of the distribution. Additionally, the existence of outliers does not affect the test results.

Another class of methods associated with nonparametrics, and often mistakenly referred to as nonparametric tests, are

distribution-free tests. Distribution-free inference, whether for testing or estimation, uses functions of the sample observations whose corresponding random variable has a distribution which does not depend on the specific distribution function of the population from which it was drawn. Order statistics have the property such that the transformation $U_{(r)} = F_X(X_{(r)})$ (where F_X is the cumulative distribution function) produces a random variable which is the r^{th} order statistic from the uniform population on the interval (0,1) regardless of the parent distribution function F_X, and therefore $U_{(r)}$ is distribution-free (Gibbons, 1985).

Appeal of nonparametric methods is due to their flexibility to the characteristics and variability of water quality data. Parametric methods require strict assumptions that most often include independence, normally distributed population and equal variance. These assumptions are commonly violated by water quality data characteristics that include nonnormal data, missing values, seasonality, values below detection limits, and serial dependence (Hirsch and Slack, 1984; Lettenmaier, 1976). Only two requirements are essential to nonparametric methods: 1) the population is continuous, and 2) random sampling is required (Gibbons, 1985; Runyon 1977). The first assumption is intrinsic to water quality. The second requirement essentially deals with independence of the data. Often water quality data are collected at a relatively constant frequency over time and serial correlation must be

considered. However, the ability to evaluate serial correlation is dependent upon the consistency and duration of sampling.

An important consideration with regard to application of nonparametric procedures is power. Power of a test is the probability that the test statistic will lead to rejection of the null hypothesis (H_o) when it is not true. With regard to trend analysis power refers to the probability of rejecting the null hypothesis (no trend exists) when trend does not actually exist. Parametric tests are more powerful than nonparametric tests when the basic assumptions of the parametric test are met. However, when these assumptions are not met nonparametric tests have been shown to be more powerful than their parametric counterparts (Harris, 1988; Hirsch and Slack, 1984).

The data analysis necessary for developing the ambient water quality representation must address four primary objectives: 1) comparison of different agency data sets at the same location, 2) identifying concentration-flow relationships, 3) detecting and quantifying seasonality, and 4) detection and quantification of trends.

Two-Sample Tests

The analysis presents two problems that require a two-sample test. Different data sets at the same location need to be compared to justify combining them into one data set and

analysis of step trends involves comparison of two different periods within the same data set. Several statistical tests can be used to evaluate the hypothesis that two random samples (data sets) come from the same population (Conover, 1980; Haan, 1977; Gibbons, 1985; Kite, 1978). The Mann-Whitney test (also called the Wilcoxon test) is considered the most powerful non-parametric tests for differences in location (Gibbons, 1985; Kite, 1978). Harris et al. (1987) and Ward et al. (1988) both recommend application of the Mann-Whitney test for analysis of groundwater quality data especially when parametric assumptions are not meet or unknown. Berryman et al. (1988) review several techniques for trend detection and conclude that the Mann-Whitney test is the best choice for step trend analysis.

The null hypothesis, H_o, is that the compared data sets are from the same population. For two random samples X_1, $X_2,...X_m$ and Y_1, $Y_2,...Y_n$, the Mann-Whitney criterion is based on the sum of the rank statistics of the Y's (or X's) in the combined ordered sequence N = m + n. The Mann-Whitney U statistic represents the number of times a Y precedes an X in the combined ordered arrangement. Large values of U indicate the Y values are generally larger than the X values and results in the rejection of the null hypothesis. When the sample sizes are large an alternative test statistic can be calculated whose distribution is approximately standard normal. The Mann-Whitney test procedure is presented in

several standard texts on statistics (Gibbons, 1985; Kite, 1978; Runyun, 1977) and is a common procedure in statistical computer analysis programs. The Mann-Whitney procedure is presented in the Appendix.

Concentration-Flow Relationships

Correlations between river flow and concentration of water quality parameters have been studied by several researchers (Delfino, 1977; Hull et al., 1981; Noss and Gladstone, 1987; Smith et al., 1982). The actual correlation will vary from one river system to the next and between different water quality parameters. The existence of a correlation between concentration and flow on any given river system usually follows one of two characteristic responses, a dilution effect or a wash-off (erosion) effect (Hirsch et al., 1991; Lettenmaier et al., 1991; Smith et al., 1982). The dilution effect is characterized by a decrease in concentration with increasing flow (negative correlation) and is normally associated with dissolved constituents. The dilution effect is typically associated with water quality parameters where the main source is relatively constant, such as a point source discharge or a constant base flow from an underground aquifer.

The wash-off/erosion effect is characterized by increases in concentration with increasing flow (positive correlation) and is normally associated with sediment and parameters that

are attached to sediment. The primary sources for increasing concentration with flow are overland flow and stream bank erosion. Certain conditions can lead to both responses (dilution and wash-off) for a specific parameter (Smith et al., 1982), where the initial increase in discharge has a dilution effect but as the discharge continues to increase the concentration increases with increased wash-off and erosion.

Variability of the parameter concentration due to flow is accounted for by developing a flow adjusted concentration (FAC). The FAC is calculated by first developing a relationship between concentration and flow. This relationship is then used to calculate a predicted concentration based on the measured flow. The FAC is then calculated by subtracting the predicted concentration from the actual measured concentration. Several relationships between concentration and flow have been used to develop FACs for analysis of trends in water quality (Lettenmaier et al., 1991; Hirsch et al., 1991; Spooner, 1990; Smith et al., 1982). All of the methods identified except one use linear regression to estimate the coefficients of the relationship. Linear regression is conducted using least squares analysis which is not a nonparametric procedure. However, it does provide an accepted procedure to account for variability due to flow. The other method described by Lettenmaier, et al. (1991) is a locally weighted regression technique that uses a nonlinear smoothing algorithm developed by Cleveland (1979). The data analysis

procedure does not incorporate the smoothing technique. The functional relationships used in the data analysis are given in Table 3-1.

Table 3-1. Concentration-Flow Functional Relationships

Functional Relationship	Equation
linear	$C = a + bQ$
log-linear	$C = a + b(\ln Q)$
hyperbolic	$C = a + b(1/1+\beta Q)$
inverse	$C = a + b(1/Q)$
quadratic	$C = a + b_1Q + b_2Q^2$
exponential	$\ln C = a + bQ$
log-log	$\ln C = a + b(\ln Q)$
log-quadratic-log	$\ln C = a + b_1(\ln Q) + b_2(\ln Q)^2$

The parameters for each of the relationships are determined using linear or multiple linear regression, except for beta (β) in the hyperbolic function. Eight values of β are used resulting in eight possible hyperbolic equations. β is initially estimated as a function of the integer portion of $\log_{10}Q$;

$$\beta = 10^{-2.5(\mathrm{INT}(\log Q))}$$

where logQ is base 10. β is then incremented by a factor of $10^{0.5}$ for each subsequent regression.

Significance of the various regressions is determined by evaluating the null hypothesis, H_o: $b = 0$, or the assumption that the slope of the regression line equal zero. The regression is considered significant for $p < 0.05$. Selection

of the appropriate regression is based on the following considerations:

1. whether concentration increases or decreases with flow,
2. do the data exhibit heterogeneity of variance (varying levels of variance over the range of discharges),
3. the r^2 and p values for the functional forms evaluated,
4. homogeneity of the FAC residuals, and
5. the function must predict realistic concentrations over the range of flows (e.g., no zero concentrations).

Seasonal Analysis

Seasonality within the data is characterized by an annual cycle where the mean and or variance of one season (monthly, bimonthly, or quarterly) is different from the mean or variance of the next season. These seasonal variations can be a consequence of both natural activity (biological) and managed activity (agriculture or process management). Additionally, changes in river flow and the source of river flow are seasonal and impart seasonal characteristics to the water quality data. Although, removal of variations due to flow by calculating FACs does remove some seasonality, Hirsch et al. (1991) show that in some cases seasonality does remain in the flow adjusted data.

The analysis required for developing ambient water quality is both detection and quantification of seasonality. In traditional time series analysis, specific detection of periodicities (seasonal cycles) within the data is accomplished by spectral analysis (Brockwell and Davis, 1987; Chatfield, 1984). Spectral analysis assumes equally spaced data which is not a common characteristic for water quality data. With respect to nonparametric statistical analysis, detection of seasonality becomes a two-sample or multiple-sample comparison. If prior knowledge indicates that one season is different from the others, a two-sample test such as the Mann-Whitney test can be applied. When seasonal characteristics are not known, multiple seasons are usually anticipated. The Kruskal-Wallis test is used to detect differences in the medians between several samples (multiple seasons). This procedure is simply an extension of the Mann-Whitney test to more than two data sets and is described in several texts (Kite, 1978; Conover, 1980; Gibbons, 1985). If one or more of the seasonal medians is significantly different from the others, the test statistic indicates significant seasonality. The Kruskal-Wallis test has the same power characteristics as the Mann-Whitney test (Harris et al., 1987). Harris (1988) and Phillips et al. (1989) both recommend the Kruskal-Wallis test for detection of seasonality. The Kruskal-Wallis test procedure is presented in the Appendix.

The Kruskal-Wallis test does not provide a quantitative measure of seasonality. In time series analysis seasonality is quantified and removed using various methods including: 1) moving average filter, 2) differencing, and 3) sine or cosine functions. These methods rely on a continuous time series with constant time intervals between data points (Chatfield, 1975; Brockwell and Davis, 1987; Montgomery and Reckhow, 1984) and are not generally applicable to water quality data. The simplest approach for estimating the seasonal component is to calculate the overall mean and variance for each seasonal period. The simple calculation of seasonal means is readily applicable to time series that exhibit little or no trend (Brockwell and Davis, 1987). Where significant trend exists it must be removed prior to estimation of the seasonal components. In addition to seasonal means it is suspected that variance of the data is also seasonal. Subsequently the seasonal component includes a seasonal mean and variance.

A common graphical procedure used to evaluate seasonality is the development of seasonal box-whiskers plots (Ward et al., 1988). These plots have three components: 1) the median represented by the center line in the box, 2) the interquartiles or middle 50% of the data represented by the box, and 3) the maximum and minimum values represented by the whiskers. The plots are interpreted by comparing the location and size of the boxes on the plots. Significant seasonality in the calculated medians is indicated when the boxes do not

overlap, while differences in the length of the boxes indicates possible seasonality in the variance (Phillips et al., 1989). Box-whiskers plots provide a graphical means of interpreting seasonality.

Trend Analysis

The specific method selected for the analysis depends on the type of trend present. Water quality data are commonly evaluated for two types of trend; monotonic trend (uniformly increasing or decreasing) and step trend. Methods for trend analysis of water quality data and their application have been well documented over the past ten years (Hirsch et al., 1982; Hirsch and Slack, 1984; Hirsch, 1988; Hirsch et al., 1991; Lettenmaier et al., 1991; Reckhow and Stow, 1990; Smith et al., 1982; van Belle and Hughes, 1984). Berryman et al. (1988), provide a review of nonparametric methods for trend analysis and conclude that Mann-Whitney, Spearman, and Kendall tests are the best choice for trend detection in water quality time series.

Several methods for evaluating step trends are presented by Hirsch (1988) and Phillips et al. (1989). Two common nonparametric procedures are the Wilcoxon Signed Rank test and the Mann-Whitney test. The Wilcoxon Signed Rank test is designed for comparing two data sets with paired values. This requires each data set to have the same number of data points. The Mann-Whitney test is a similar test but allows for the

analysis of unpaired data sets. The Mann-Whitney test provides the flexibility needed to compare different time periods with different sampling frequencies.

The method most often applied for evaluation of monotonic trend in water quality data is the seasonal Kendall test described by Hirsch et al.(1982) and Hirsch and Slack (1984). This test is distribution free and not affected by seasonality which makes it highly applicable to analyzing water quality data. The Kendall test compares all possible pairs of data values and assigns a rank of plus one if the later value in time is higher and a negative one if it is lower. If no trend is present, the sum of the pluses and minuses should equal zero or be relatively close to zero. Seasonality is taken into consideration by conducting the rankings and summing over each season individually. The seasonal Kendall test statistic is then calculated as the sum of the individual seasonal rank sums and converted to a standard normal test statistic using the mean and variance. A detailed description of the test can be found in Hirsch et al. (1982). The seasonal Kendall test procedure is presented in the Appendix.

The seasonal Kendall test only indicates whether or not a trend exists and does not determine the magnitude of the trend. To complement the seasonal Kendall test for trend, Hirsch et al. (1982) present the seasonal Kendall slope estimator which is a modification of the slope estimate developed by Sen (1968) to account for seasonality. The slope

estimator is the median of the differences of the ordered pairs evaluated for the Seasonal Kendall trend test and quantifies the magnitude of the trend.

Serial Correlation

The most difficult consideration for the analysis of water quality data is that of serial correlation. The statistical methods described make the assumption of independent data. Water quality data often exhibit persistence over time where the measurement at one time period will have a tendency to be high if the concentration observed at the previous time period was high. This persistence is commonly referred to as serial correlation or autocorrelation. Several investigators have evaluated the effect of serial correlation on the power of statistical tests (Berryman et al., 1988; Harris, 1988; Hirsch and Slack, 1984; Lettenmaier, 1976). Lettenmaier (1976) presented a power function for the Mann-Whitney test based on a parameterized statistic called the dimensionless trend number, N_T. N_T is parameterized based on the assumption of normality. The power function is developed for daily sampling frequency and lag 1 Markov dependence and provides an estimate of the number of samples necessary to detect specific levels of trend. Montgomery and Reckhow (1984) use the power function developed by Lettenmeir (1976) to develop a series of empirical correction factors that are used to adjust the critical levels of the statistical

tests. Use of the methods developed by Lettenmeir (1976) and Mongomery and Reckhow (1984) require the ability to estimate the lag 1 correlation coefficient for daily water quality data. Hirsch and Slack (1984) propose a modification to the original Seasonal Kendal test (Hirsch et al., 1982) to account for serial correlation in calculation of the test statistic (See Appendix). Application of the correction for serial correlation does not require estimation of the correlation structure. However, Hirsch and Slack (1984) show that application of the correction to data sets with monthly sampling frequency and less than ten years of record greatly reduces the power to detect trends and recommend that the correction only be used for data sets ≥ ten years of record. The original test is recommended when less than ten years of record are available.

Hirsch and Slack (1984) point out the difficulty of differentiating between trend and persistence for any technique when the degree of serial correlation is high. More importantly, Loftis et al. (1991) identify the need to understand the effect of serial correlation with regard to the time scale of the estimations and statistical analysis. The distinction between serial correlation and trend is much more difficult over short time periods than over long time periods. The existence of serial correlation basically requires larger sample sizes to achieve a desired level of precision (Lettenmaier, 1976; Loftis et al., 1991). Berryman et al.

(1988) present a review of nonparametric tests for trend and make several informative conclusions: 1) tests for series with dependence are less power than tests for series without persistence, 2) the test significance is smaller than its nominal level (conservative) for application of the classic tests under conditions of dependence, and 3) the more classic tests can be applied in the presence of modest amounts of dependence. Thus, in the presence of modest amounts of dependence, the loss in power for application of tests for dependence is likely greater than the gain in exactness of the test significance.

The ability to evaluate serial correlation within water quality data is often limited. The primary objective of the research on serial correlation and statistical detection methods is to improve and optimize water quality monitoring programs. Again, the development of ambient water quality is limited to available historical data that is characterized by infrequent and variable sampling that makes it impractical to estimate the correlation structure, especially on a daily basis. An understanding of the effect of serial correlation is essential in the interpretation of the data analysis results.

Formalized Data Analysis

Formalized approaches to water quality data analysis are based on the objectives of the analysis. Reckhow and Stow

(1990) present a formalized approach for monitoring design with an objective to estimate the number of samples necessary (sampling frequency) to detect specific levels of trend. This approach can be summarized in four general steps: 1) data analysis for detection and numerical definition of seasonality and concentration-flow relationships, 2) removal of deterministic components (seasonality and flow variability) from the data, examination of residuals for stationarity and transformation as necessary to obtain stationarity, and 4) use variance of residuals to estimate sampling frequency required to detect various magnitudes of trend.

Several researchers have discussed the methods and approach to trend analysis (Berryman et al., 1988; Hirsh et al., 1982; Hirsch and Slack, 1984; Lettenmaier, 1976; Lettenmaier et al., 1991; Montgomery and Reckhow, 1984; van Belle and Hughes, 1984). Hirsch et al. (1991) provide a general summary of the approach to trend analysis that consists of four steps: 1) trend type to be analyzed step versus monotonic, 2) selection of statistical methods, 3) kind of data to analyze concentration versus flux data, and 4) data manipulations for removal of natural sources of variability (seasonality and flow) and considerations for censored data (below detection limit).

Ward et al. (1988) present a data analysis protocol for assessment of ground water quality data and identify the objectives and benefit from a formalized approach to data

analysis: 1) to make informed water quality management decisions, 2) provide a scientifically defensible description of the water quality behavior, 3) ensure a consistent approach to analysis when different analysts are involved, and 4) provide a means of tracking the analysis for verification of results and conclusions.

Literature with regard to data analysis to represent ambient water quality for development of antidegradation criteria is limited. A few states have developed antidegradation criteria, but focus on the numerical representation of the criteria versus analysis of the ambient data to be used for developing the criteria. The Nevada Division of Environmental Protection (NDEP, 1987) used all available data from several sources to develop "Requirements to Maintain Existing Higher Quality"(RMQH). RMQH's were developed based on the complete data record and the most recent three year period in an effort to recognize recent possible improvements in water quality. No other preparatory analysis of the data was reported (NDEP, 1987). Data analysis for development of water quality criteria for Hawaii and American Samosa consisted of selecting "healthy" sites and separation of the data into three seasonal time periods: wet, seasonally wet, and dry (Hawaii Department of Health, 1977; Krock and Sullivan, 1986).

Breidt et al. (1991) present a good description of the data analysis used to develop a distribution free represen-

tation of antidegradation water quality criteria. The data analysis included evaluation of time series plots, data density, seasonality and trend. However, data sets that exhibited trend, seasonality or regime shifts were eliminated from analysis for development of the water quality criteria (Breidt et al, 1991). Two deficiencies in this approach are 1) eliminating data with trend, seasonality or regime shifts neglects the deterministic components that are part of the natural characteristics of water quality and are subsequently not represented in the criteria, and 2) when the only data available for a specific parameter or location exhibit trend or seasonality no criteria would be developed. In fact, Breidt et al. (1991) reduced their data set for analysis from thirty-six to twelve parameters.

The approach presented in this research has a primary objective of using, justifiably, as much of the available data as possible and representing deterministic components within the water quality criteria.

Data Analysis Protocol

Analysis Objectives

The objective of the analysis is to develop a data set that represents ambient water quality conditions with respect to a defined baseline time period. The numerical definition of ambient water quality must incorporate natural variability, while variability due to anthropogenic impacts is quantified

and removed from the data. Natural variability is defined by analyzing seasonal cycles and concentration/flow relationships. Anthropogenic impacts are defined by evaluating changes in water quality over time (trend analysis) with respect to a baseline time period. Typically the baseline time period will be the current time period or some earlier time period that is defined by regulations. When the baseline time period represents an earlier time, it is possible that water quality may have improved since that time. This approach analyzes the compiled data to define ambient water quality as the better water quality of either 1) the baseline time period, or 2) that which has existed since the baseline time period.

To provide the benefit of a formalized "data analysis protocol" (Ward et al., 1988) for the evaluation of additional parameters and monitoring locations, a four step approach to the data preparation and analysis has been established. The four major steps of the DAP are:

a. data set aggregation at each monitoring location,

b. concentration versus flow regression analysis,

c. evaluation of seasonality, and

d. water quality trend analysis.

A general flow diagram outlining the sequence of procedures for the DAP is given in Figure 3-1. At each step the data are evaluated using qualitative and quantitative methods to prepare the data for subsequent stages of analysis. Each step

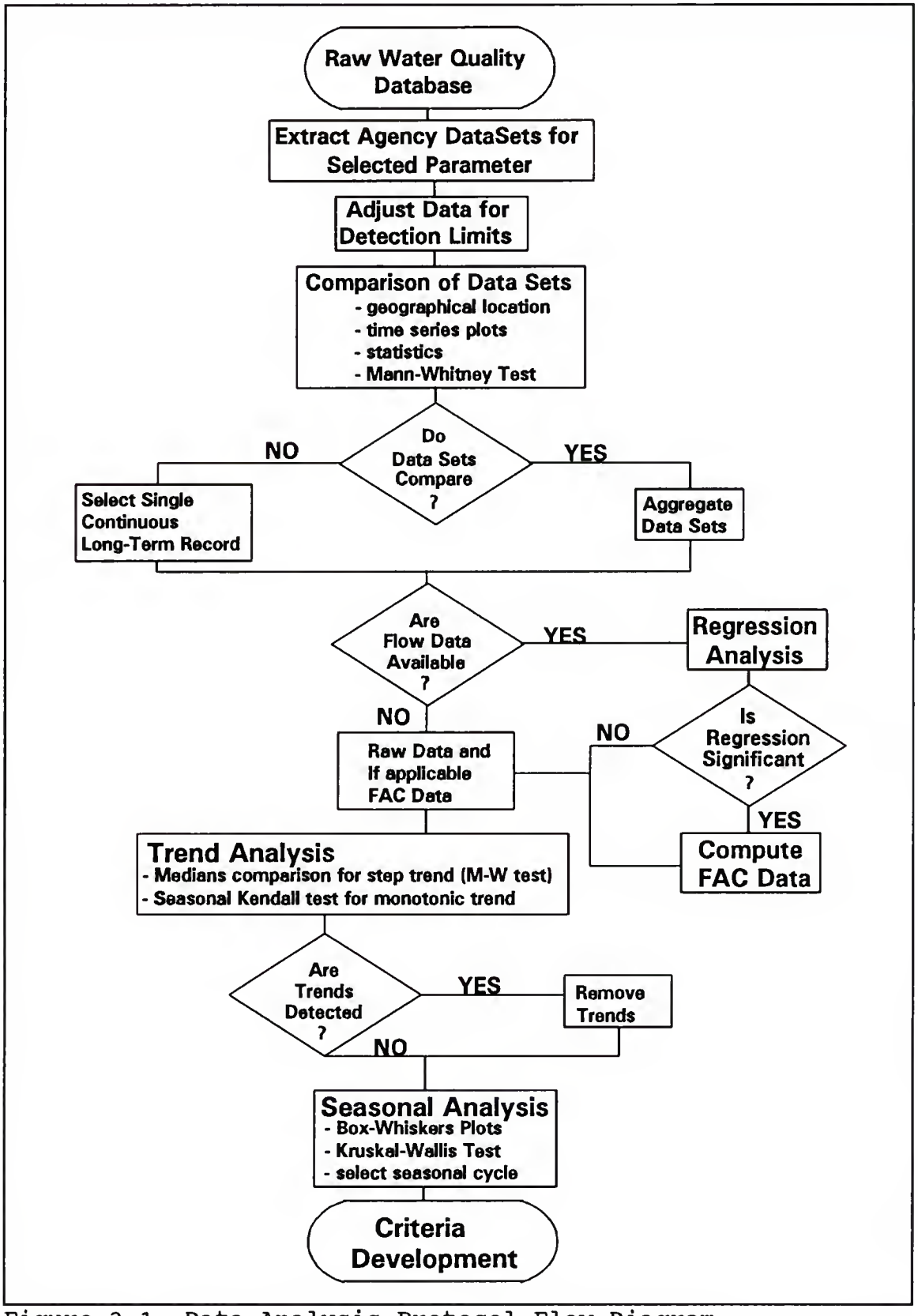

Figure 3-1. Data Analysis Protocol Flow Diagram

requires a decision regarding representation of the data and no individual analytical or statistical method provides a complete definitive answer. Consequently, the information from all the methods used is combined to make an informed judgement regarding the characteristics of the data.

Data Aggregation

The objective of data aggregation is to compare and combine where justified, the data collected by various agencies forming a single data set at a specific monitoring location. The data sets at each location are evaluated and compared using a four step procedure. The first two steps are qualitative by nature while the other two are quantitative.

Geographical orientation and location. The purpose of this step is to identify sampling location relationships to tributaries and point source discharges. Tributaries and point discharges into the river can have a significant effect on the receiving water quality. A monitoring station located at the mouth of a discharge or tributary will likely characterize the mixing of the two water bodies versus the true ambient nature of the receiving water. Monitoring stations that more closely reflect the tributary (or discharge) should not be included for further analysis. Also, some monitoring stations are located upstream while others might be located downstream of a discharge or tributary. In order to identify and represent their impacts on water quality, the data

collected by the agencies at stations above and below tributaries and point sources should be separated for comparison. Upstream and downstream data sets should be compared and where no difference is identified the data sets can be combined into one data set.

This step requires obtaining as much specific information as possible about the sampling location and plotting the locations on a detailed map of the area. The map should clearly indicate tributaries and point source discharges.

Time series plots. A fundamental step to any analysis of data is a graphical representation. Time series plots of the data provide a means of visual comparison and interpretation of the data. For each parameter at each location, a single time series plot is made with the data for each agency represented.

The time series plots are used to visually compare the sampling period of record, apparent trends, outliers and general differences in measured concentrations over the period of record. As previously discussed, the time series plots also show that sampling frequency varies over the period of record. Initially, significant differences in the measured concentrations for one data set compared to the other agencies at a given location identifies the possibility of significant differences that require further investigation of that particular data set.

Standard statistics. As the title suggests, this step comprises computation of the standard statistics: minimum, mean, maximum, standard deviation, coefficient of variation and sample size. The statistics for each data set at a specific location provide for a numerical characterization of the data. Visual differences apparent in the time series plots are quantified by these statistics. The skew coefficient provides a quantitative measure of whether or not the data might be normal, noting that the skew of a normal distribution is zero. The mean provides a measure of central tendency and the standard deviation represents the spread of the data. These standard statistics can be highly influenced by a single high measurement indicating differences in the data. Subsequently, the nonparametric Mann-Whitney procedure, which is not influenced by one or two high measurements, is used for comparing the data sets.

Mann-Whitney test. The Mann-Whitney test is used to provide a statistical comparison of the different agency data sets at a given location. The purpose of the comparison is to identify possible differences due to sampling and analytical procedures. The null hypothesis for the test is that the two data sets compared are not different (e.g. come from the sample population). The rejection region for H_o is when the absolute value of the calculated test statistic is greater than $Z_{\alpha/2}$, based on a two-tailed probability (p) of α (confidence level of $1-\alpha$). If the two-tailed probability is

greater than α, then the hypothesis that the data sets come from the same population is not rejected. The significance level, α, is chosen by the analyst and a value of 0.05 is recommended. As the calculated value for p increases the significance of the comparison increases.

Differences in sampling and analytical procedures are not the only possible source of variability that can cause the Mann-Whitney test to reject the comparison of two data sets. Data from different time periods can vary due to trends in water quality or due to differences in flow regime (e.g., drought conditions). Comparison of data collected from the same time period will reduce the effect of variability due to different periods of record and provide a better representation of possible differences between agencies. Based on an understanding of the sampling frequency and period of record the Mann-Whitney test should be done for complete records and for similar periods of record between two data sets.

Data adjustments. The raw data are adjusted for outliers, multiple daily samples (laboratory replicates), values reported as below detection limits (censored data), and where justified different agency data sets combined into one data set. If outliers are identified in the data they can be removed. Identifying and removing outliers should be done with careful consideration of whether it represents a mistake or an actual value. Multiple daily samples are averaged to represent one daily value.

The nonparametric procedures used in the analysis are not affected by censored data (Hirsch et al., 1982; Ward et al., 1988). Adjustment of censored data is basically a preference choice by the analyst. Two common adjustments are: 1) to set all censored data equal to one half the detection limit, or 2) set all censored data equal to a value just below the detection limit. When combining different data sets the minimum detection level for a given parameter might not be the same or the detection level can change over the period of record. When combining the data sets the controlling minimum detection level is the highest detection level. All censored data over the period of record and from each data set combined should be adjusted to the highest minimum detection level.

Based on the information obtained from this analysis step the data sets are combined into one representative data set for each specific parameter and location.

Concentration Flow Relationships

The concentration-flow relationship analysis provides information for characterizing the type of source associated with the water quality parameter and to develop FACs for the trend analysis.

This step is fairly straight forward, however it is only applicable where flow data are available. Daily flow data are paired with water quality measurements for the same dates. The functional relationships given in Table 3-1 are applied

and evaluated. When a significant correlation between concentration and flow exists the best functional relationship is chosen and FACs are calculated according to equation 3. The best fit functional relationship might not necessarily be the best regression fit. The functional relationship must be physically justifiable in that it should not predict negative concentrations for flow value within the possible range of values. The FACs are used for the trend analysis. Additionally, the functional relationship with flow can be used in the development of the criteria.

Trends

Trend analysis is necessary to evaluate changes in water quality that have occurred over time due to various impacts within the basin (point and nonpoint source discharges) with respect to the baseline year. These types of changes in water quality do not reflect ambient conditions for the baseline year. If trends in the data are identified, they are removed from the data to represent ambient conditions for the baseline year. For the trend analysis a baseline time period must be selected. The baseline year is used as a reference point, but does not imply any physical change occurred in the basin at that time. The baseline time period will most likely be based on specific regulations and typically will be the current time period or reference some earlier time period.

The method used for the trend analysis, seasonal Kendall or Mann-Whitney, will depend on the type of trend to be evaluated. The Mann-Whitney test is used to evaluate step trend and the seasonal Kendall test is used to evaluate monotonic trend. Analysis for step trend applies to two general cases: 1) when a specific event in time is known such as a new point source is added or significant changes in a treatment process occur, and 2) when there is a long gap in the data. A monotonic trend is characterized by gradual increasing or decreasing change over time. The decision to evaluate for step trend or monotonic trend is based primarily on visual characteristics of the time series plots for each parameter.

The Mann-Whitney test is applied as described in the data aggregation step. The seasonal Kendall test evaluates the significance of an apparent trend (increase or decrease) in concentration over time. The null hypothesis, H_o, is that no change has occurred. Because both increasing and decreasing trend are possible a two sided probability is used for the test. The significance level, α, is selected by the analyst. The recommended significance level is 0.05, with a corresponding confidence level of 95%.

To understand the identified water quality changes and obtain as much information as possible three general time periods are evaluated: 1) the entire period of record, 2) the record from the earliest date up to the baseline year, and 3)

the record starting at the baseline year to the most recent available data. However, based on the actual period of record, type of trends, pollution sources, and basin characteristics the specific periods evaluated will vary. As necessary, other time periods should be evaluated. Results from the trend analysis of these three time periods will assist in making judgements regarding detrending of data to establish the baseline ambient water quality.

In addition to detecting and identifying the significance of the trend, the magnitude of the trend is calculated. The magnitude of the step trend between two time periods is estimated by the difference in medians. The magnitude of a monotonic trend is determined by the seasonal Kendall slope estimator or Sen slope estimator (Hirsch et al., 1982).

Data adjustment. Where the identified trends do not reflect ambient water quality of the baseline year the data are detrended. Recall the objective of the analysis is to represent the ambient water quality as the better water quality of either 1) the baseline time period, or 2) that which has existed since the baseline time period. When the baseline year represents the best water quality the data are detrended using the baseline year as the reference. For example, if the water quality prior to the baseline year is better it is adjusted upward to represent the baseline time period. Conversely, if water quality has improved since the

baseline year, the data are adjusted to represent the better water quality.

Seasonal Analysis

The analysis of seasonality consists of two primary steps: 1) selection and determination of the most significant seasonal period, and 2) numerical calculation of the seasonal components (mean and standard deviation). Representation of each parameter, at each location, with its corresponding significant quarterly cycle would require development of numerous seasonal relationships and subsequent criteria. The seasonal analysis presented here identifies the most consistent quarterly seasonal cycle within the data for use at all locations for all parameters. The seasonal analysis uses box-whiskers plots and the Kruskal-Wallis test. The null hypothesis, H_o, for the Kruskal-Wallis test is that the data are all independent and identically distributed (no seasonality exists). The null hypothesis is rejected if any two seasons are significantly different. Similar to the Mann-Whitney test a two tailed probability is used with significance level of α.

Selection of the appropriate seasonal cycle is related to the variability and sampling frequency of the water quality data. To represent monthly seasonality the sampling frequency must be equal to or greater than monthly. When the sampling frequency varies over the period of record, the minimum common

sampling frequency should be the basis for the seasonal cycle to be used.

If the selected seasonality is greater than twelve months, it is appropriate to conduct an analysis to determine the most significant seasonal cycle. For example, if quarterly seasons are selected there are three possible quarterly cycles which are shown in Table 3-2. The most significant seasonality is determined by the largest significance of the Kruskal-Wallis test on each cycle. For the selected seasonal cycle the mean and standard deviation for each season are calculated from the detrended data.

Table 3-2. Quarterly Seasonal Cycles

Quarter	Cycle 1	Cycle 2	Cycle 3
1	Jan 1 to Mar 31	Feb 1 to Apr 30	Mar 1 to May 31
2	Apr 1 to Jun 30	May 1 to Jul 31	Jun 1 to Aug 30
3	Jul 1 to Sep 30	Aug 1 to Oct 31	Sep 1 to Nov 30
4	Oct 1 to Dec 31	Nov 1 to Jan 31	Dec 1 to Feb 29

Ambient Water Quality

The result of the data preparation and analysis presented above provides the information necessary to represent ambient water quality and natural variability. The ambient water quality representation consists of three components: 1) detrended ambient water quality data set, 2) concentration-flow functional relationship, and 3) seasonal components represented by the mean and standard deviation.

Application To Suwannee River: Results

The data analysis protocol is used to evaluate historical water quality data for the Suwannee River. This approach is readily adapted to the analysis of surface water quality data gathered for the Suwannee. The objective for this project is to use "the best scientific information available." The data gathered and reviewed represent the best available information for describing the ambient water quality of the Suwannee River. As much of the available data as possible is aggregated to form one composite data set at each location.

Data Aggregation

From Figure 2-1 and Table 2-1 we observe that the data sets need to be split at Ellaville and White Springs. The time series plots for specific conductance, total phosphorus and total nitrogen are presented in Figures 3-2, 3-3 and 3-4 for each location. Comparison of the different periods of record for each agency at each location identifies the 1982-1983 period as the period of record when data were consistently collected by most agencies. The complete data set 21FLA 21020006 at White Springs was excluded from further analysis for all three parameters. The statistics for each agency at each location are tabulated in Tables 3-3, 3-4 and 3-5 for specific conductance, total phosphorus, and total nitrogen respectively.

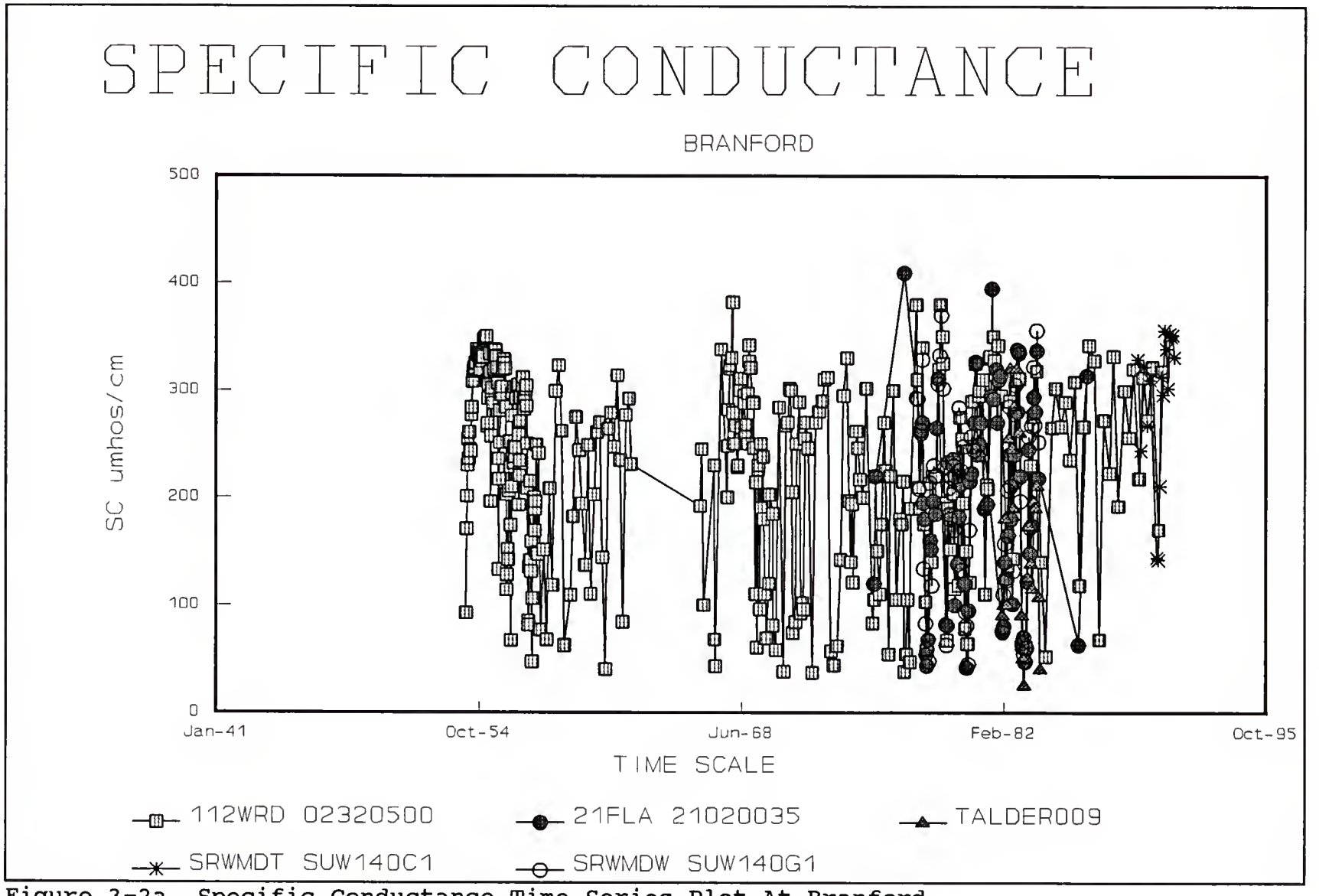

Figure 3-2a. Specific Conductance Time Series Plot At Branford

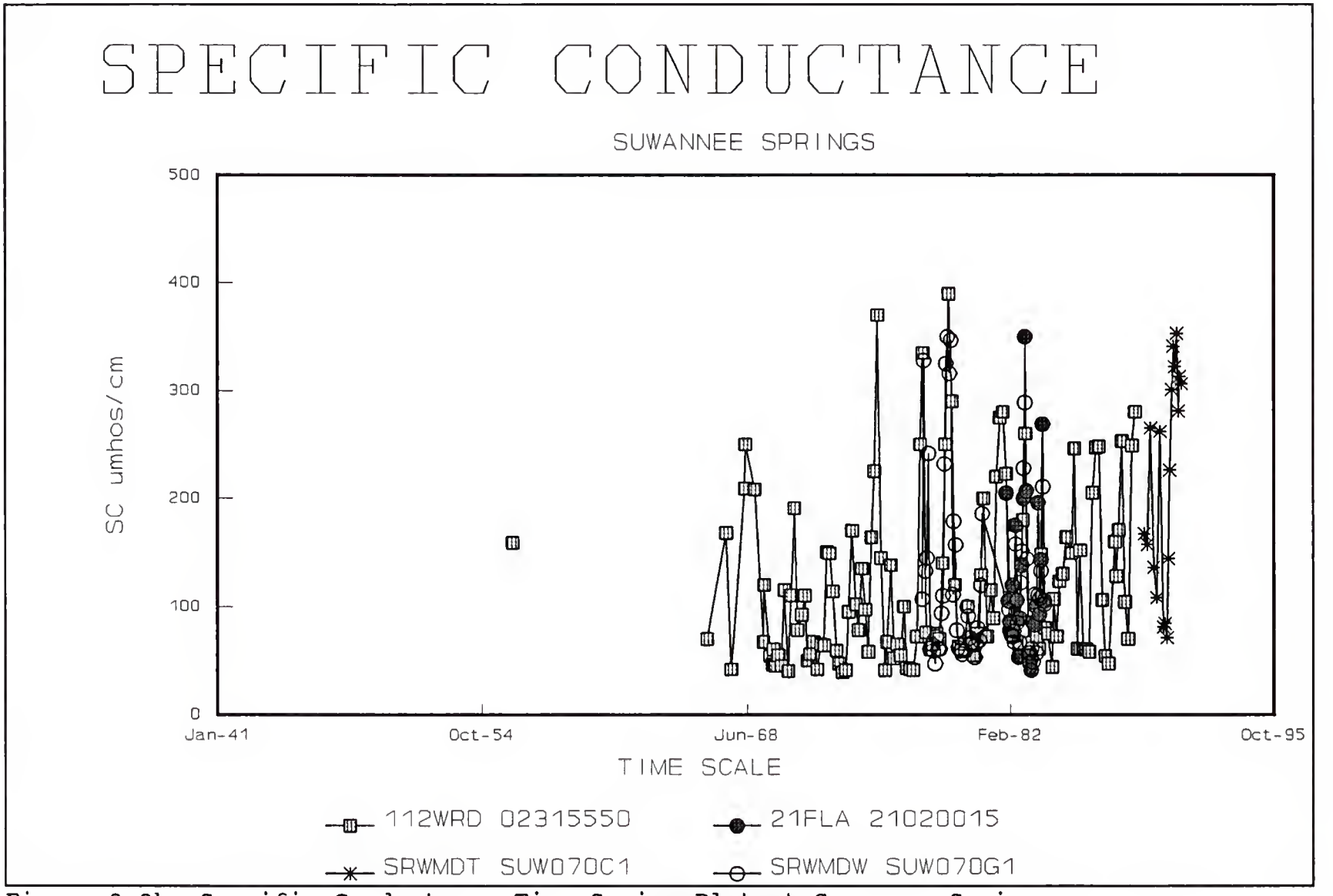

Figure 3-2b. Specific Conductance Time Series Plot at Suwannee Springs

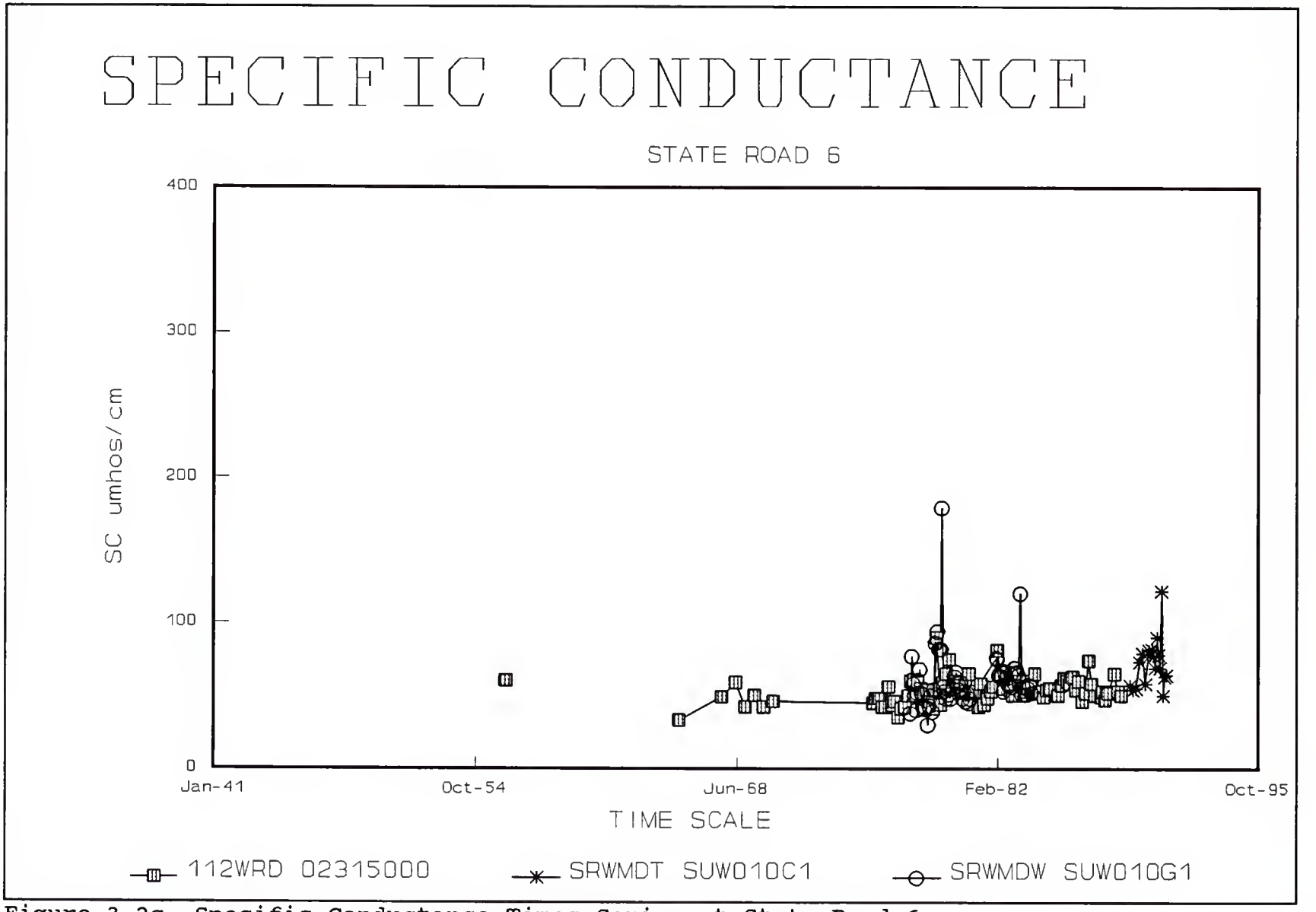

Figure 3-2c. Specific Conductance Times Series at State Road 6

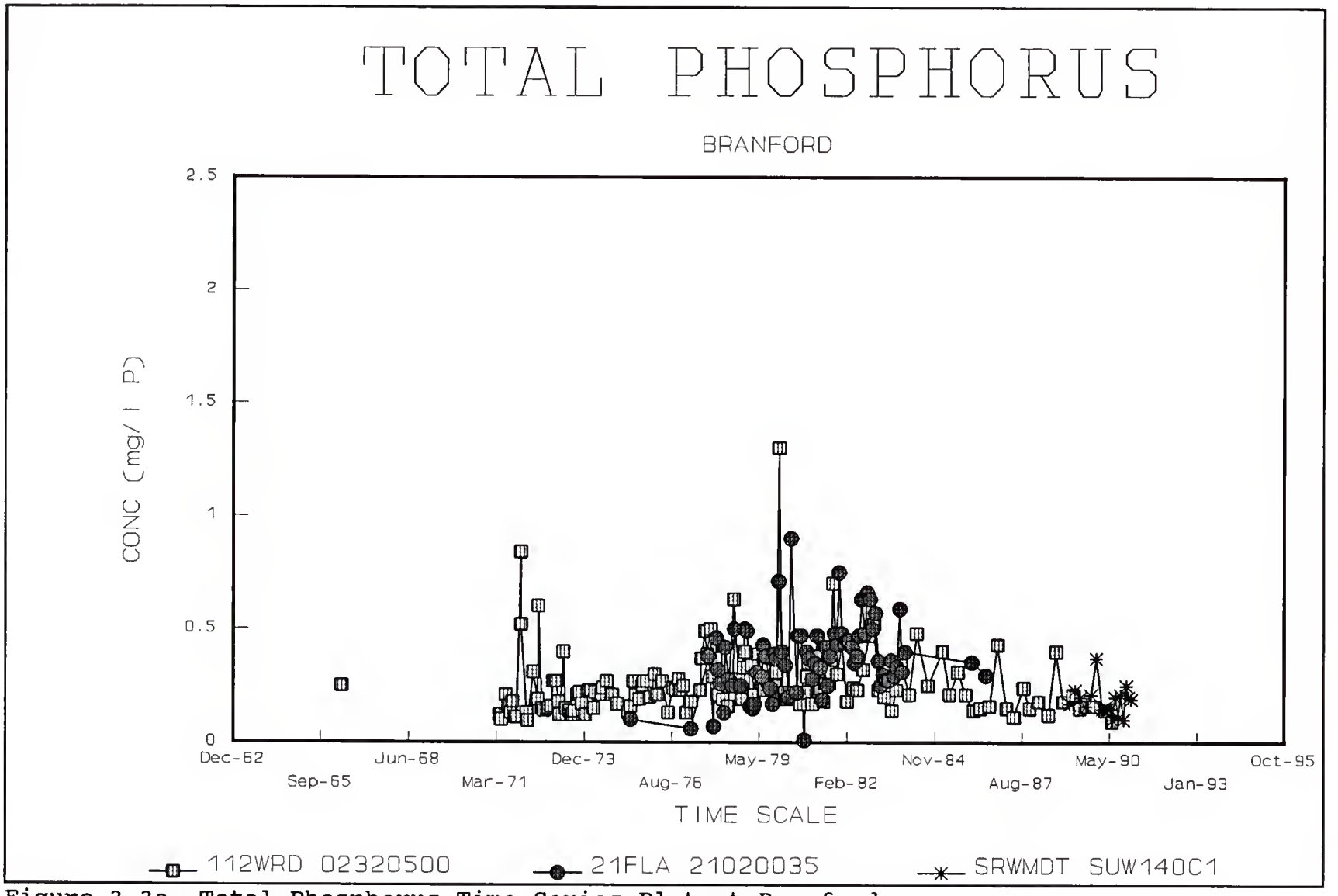

Figure 3-3a. Total Phosphorus Time Series Plot at Branford

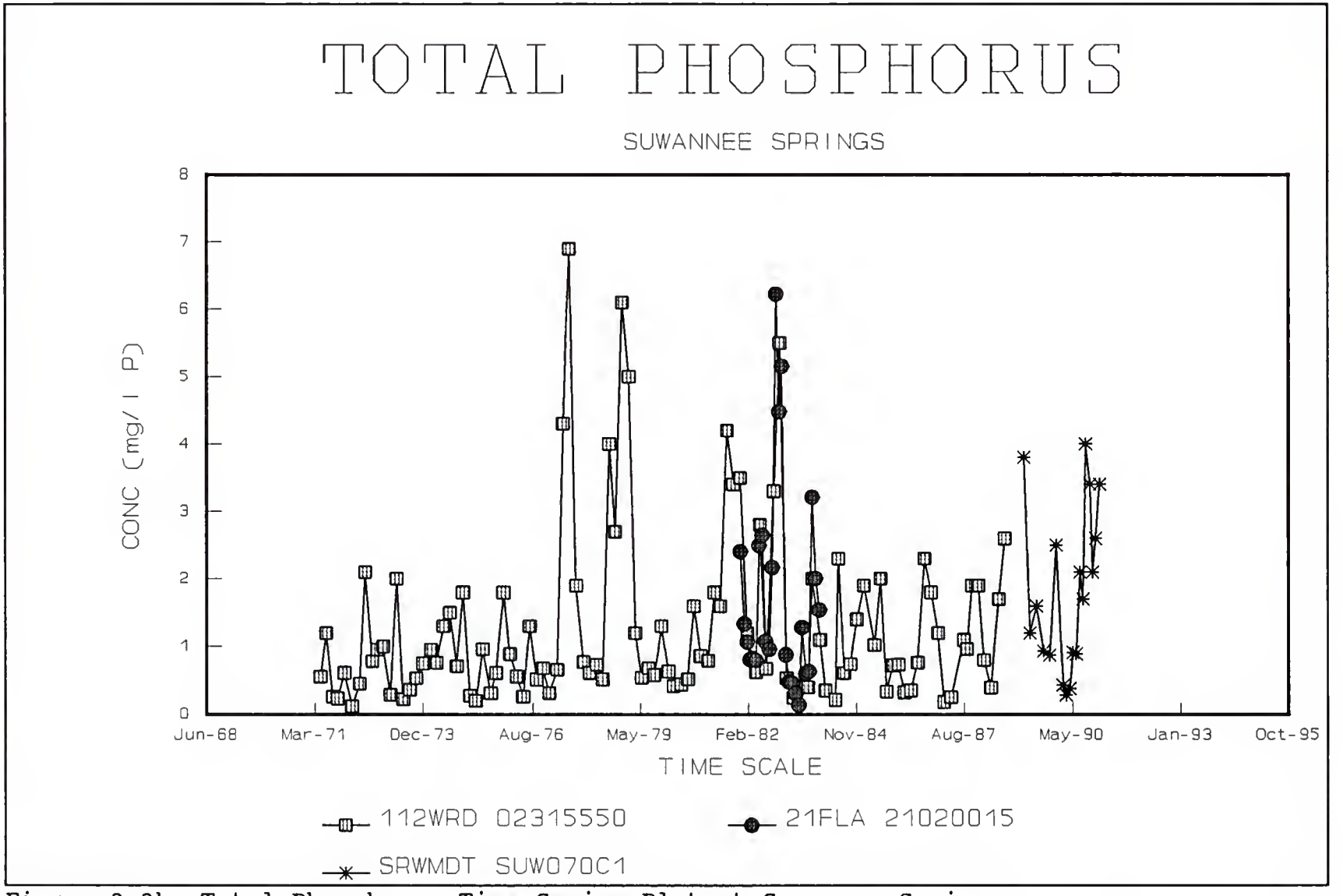

Figure 3-3b. Total Phosphorus Time Series Plot at Suwannee Springs

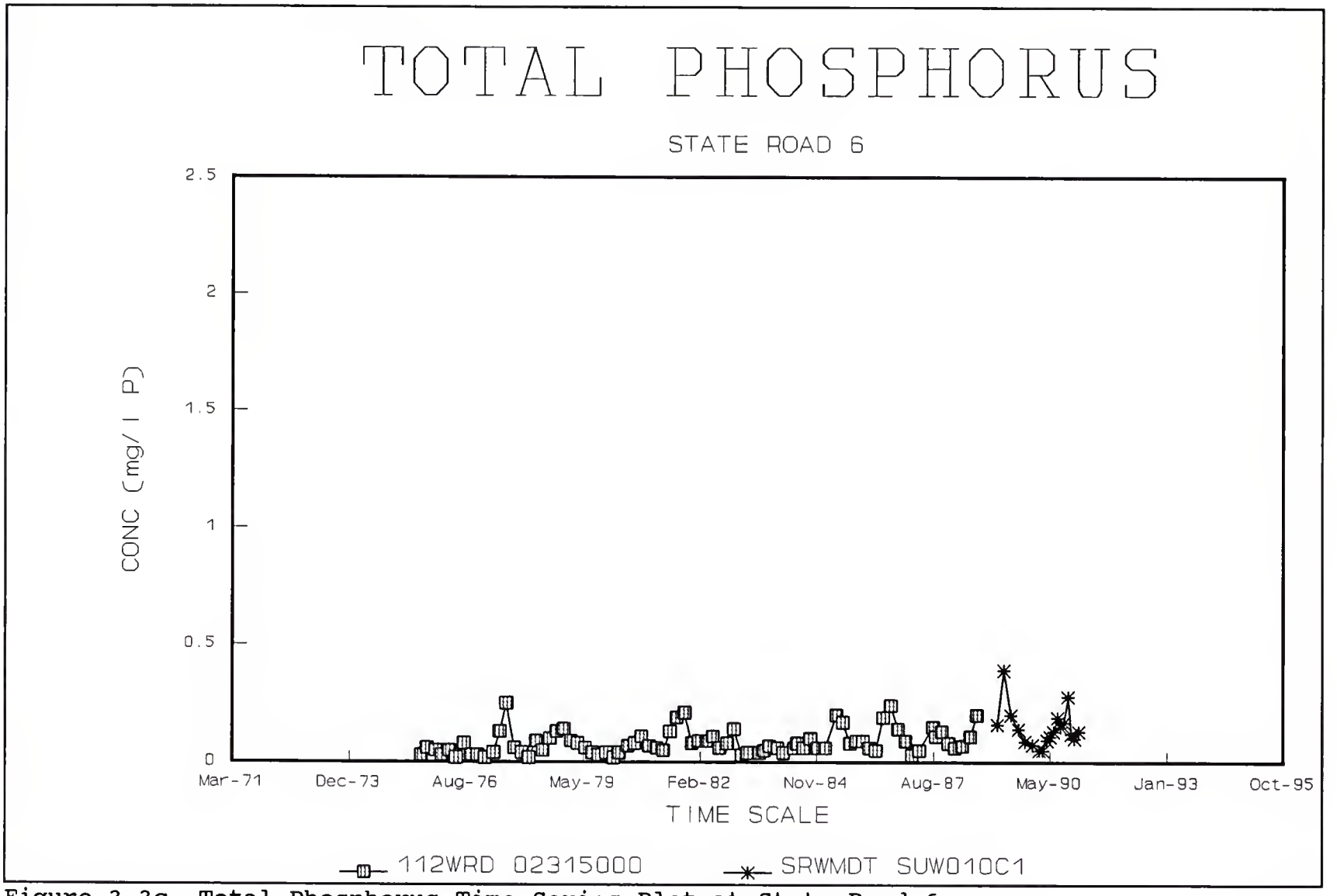

Figure 3-3c. Total Phosphorus Time Series Plot at State Road 6

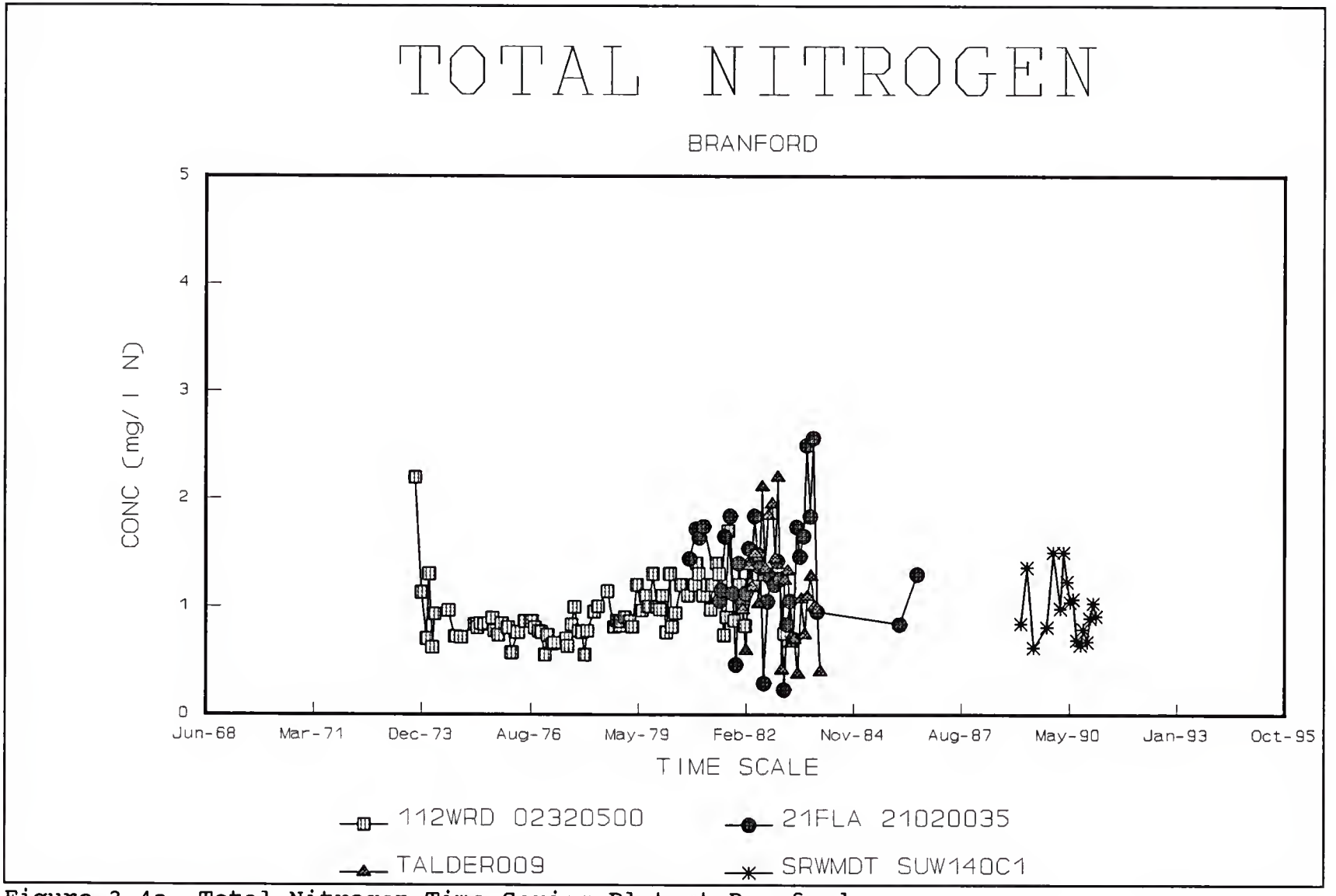

Figure 3-4a. Total Nitrogen Time Series Plot at Branford

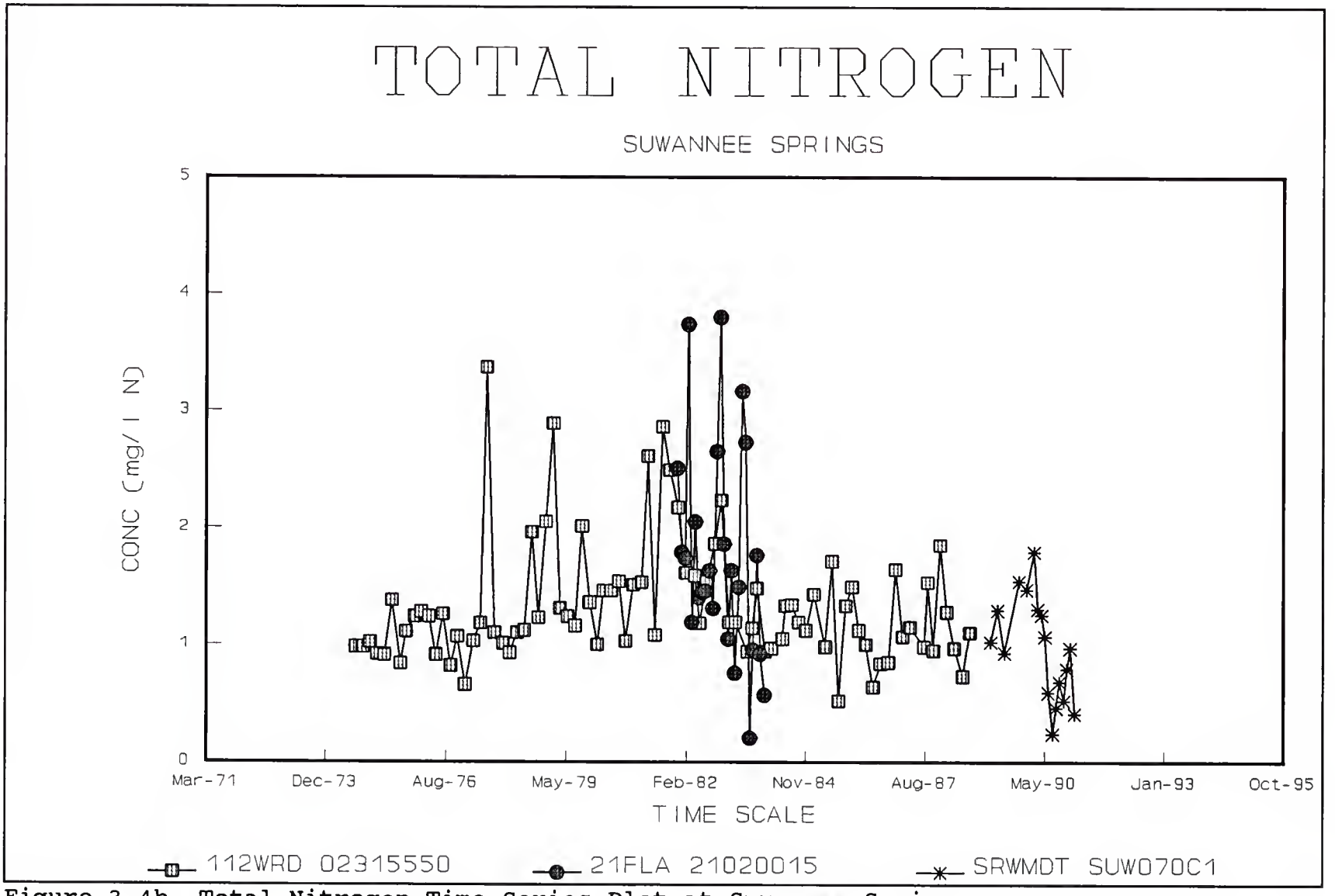

Figure 3-4b. Total Nitrogen Time Series Plot at Suwannee Springs

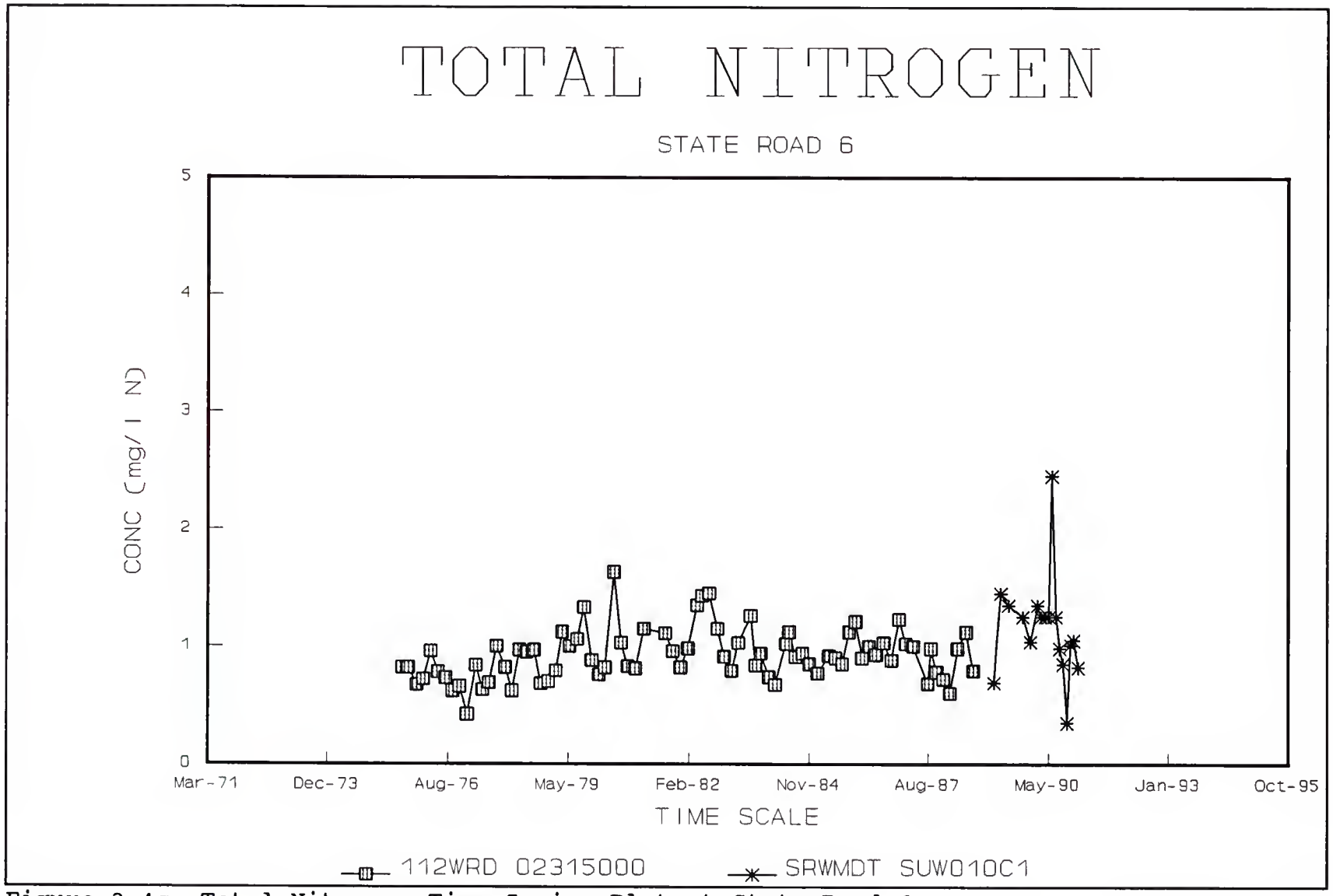

Figure 3-4c. Total Nitrogen Time Series Plot at State Road 6

Table 3-3. Summary Statistics for Specific Conductance

GROUP-ID	AGENCY	STATION	MIN	AVG	MAX	STD	CV	COUN
FOWLERS	21FLA	21020022	82	230.0	365	74.5	0.32	28
	SRWMDT	SUW240C1	170	301.8	362	65.0	0.22	12
	SRWMDW	SUW241C1	57	206.0	338	83.5	0.41	26
FANNING	112WRD	02323500	54	233.0	369	91.0	0.39	114
	SRWMDT	SUW160C1	164	313.0	360	60.5	0.19	18
	SRWMDW	SUW160G1	57	213.3	341	76.0	0.36	62
	21FLA	21020031	28	215.0	500	97.7	0.45	121
BRANFORD	SRWMDW	SUW140G1	45	203.6	370	93.0	0.46	62
	112WRD	02320500	37	233.2	382	87.2	0.37	360
	21FLA	21020035	42	201.0	410	89.7	0.45	70
	SRWMDT	SUW140C1	142	292.0	356	67.0	0.23	17
	DERTLH	TALDER009	25	165.0	320	85.0	0.52	23
LURAVILLE	SRWMDT	SUW130C1	127	274.0	348	68.5	0.25	18
	112WRD	02320000	40	207.0	317	80.0	0.39	11
	SRWMDW	SUW130C1	43	185.3	330	85.2	0.46	94
	DERTLH	TALDER008	30	154.0	310	81.4	0.53	24
	21FLA	21020034	40	182.7	360	84.0	0.46	34
ELLAVILLE	21FLA	21020014	42	163.0	270	66.5	0.41	28
	SRWMDT	SUW100C1	107	262.0	339	71.7	0.27	18
	DERTLH	TALDER006	33	145.0	282	76.0	0.52	25
	SRWMDW	SUW100G1	37	179.4	338	85.0	0.47	94
	112WRD	02319500	68	180.0	291	81.0	0.45	8
	21FLA	21010026	34	156.0	280	77.4	0.50	24
	DERTLH	TALDER005	33	145.0	282	77.5	0.53	25
	SRWMDT	SUW090C1	86	259.7	350	81.0	0.31	18
SUWANNEE	21FLA	21020015	41	128.0	350	73.0	0.57	25
	SRWMDT	SUW070C1	71	218.0	353	96.0	0.44	18
	112WRD	02315550	39	120.0	390	78.5	0.65	250
	SRWMDW	SUW070G1	47	122.2	350	81.8	0.67	62
WHITE	SRWMDW	SUW045G1	40	61.0	75	9.8	0.16	9
	SRWMDW	SUW040G1	29	61.5	147	21.0	0.34	51
	21FLA	21020042	35	63.0	145	22.6	0.36	40
	112WRD	02315500	31	58.0	135	19.3	0.33	108
	SRWMDT	SUW040C1	53	91.0	157	28.3	0.31	17
	SRWMDT	SUW030C1	53	91.4	174	28.8	0.32	18

Table 3-3. continued.

GROUP-ID	AGENCY	STATION	MIN	AVG	MAX	STD	CV	COUN
SR 6	112WRD	02315000	33	54.0	90	9.4	0.17	87
	SRWMDT	SUW010C1	50	72.1	122	16.4	0.23	18
	SRWMDW	SUW010G1	30	60.0	179	21.0	0.35	62

Table 3-4. Summary Statistics for Total Phosphorus

GROUP-ID	AGENCY	STATION	MIN	AVG	MAX	STD	CV	COUN T
FOWLERS	21FLA	21020022	0.20	0.34	0.59	0.10	0.29	29
	SRWMDT	SUW240C1	0.10	0.14	0.28	0.05	0.39	12
FANNING	112WRD	02323500	0.09	0.19	0.45	0.06	0.32	101
	SRWMDT	SUW160C1	0.05	0.13	0.28	0.05	0.38	18
	21FLA	21020031	0.02	0.27	1.10	0.02	0.06	126
8RANFORD	112WRD	02320500	0.09	0.26	1.30	0.15	0.58	147
	21FLA	21020035	0.01	0.37	0.89	0.16	0.43	75
	SRWMDT	SUW140C1	0.10	0.18	0.37	0.06	0.33	18
LURAVILLE	SRWMDT	SUW130C1	0.12	0.26	0.69	0.13	0.50	18
	21FLA	21020034	0.04	0.44	1.19	0.24	0.55	36
ELLAVILLE	21FLA	21020014	0.18	0.46	1.22	0.21	0.46	29
	SRWMDT	SUW100C1	0.13	0.26	0.40	0.09	0.35	18
	21FLA	21010026	0.17	0.73	2.07	0.41	0.56	24
	SRWMDT	SUW090C1	0.16	0.38	0.65	0.13	0.34	18
SUWANNEE	21FLA	21020015	0.13	1.76	6.23	1.54	0.88	25
	SRWMDT	SUW070C1	0.28	1.84	4.00	1.18	0.64	18
	112WRD	02315550	0.12	1.29	6.90	1.29	1.00	210
WHITE	21FLA	21020042	0.08	0.34	0.90	0.19	0.56	42
	112WRD	02315500	0.05	0.19	0.61	0.11	0.61	101
	SRWMDT	SUW040C1	0.05	0.18	0.31	0.07	0.40	18
	SRWMDT	SUW030C1	0.08	0.22	0.41	0.09	0.41	18
SR 6	112WRD	02315000	0.02	0.08	0.25	0.05	0.60	79
	SRWMDT	SUW010C1	0.05	0.15	0.39	0.08	0.53	18

Table 3-5. Summary Statistics for Nitrogen

GROUP-ID	AGENCY	STATION	MIN	AVG	MAX	STD	CV	COUNT
FOWLERS	21FLA	21020022	0.97	1.69	2.45	0.41	0.24	25
	SRWMDT	SUW240C1	0.68	0.91	1.23	0.19	0.21	11
FANNING	112WRD	02323500	0.38	0.91	1.39	0.21	0.37	81
	SRWMDT	SUW160C1	0.53	0.90	1.63	0.29	0.32	17
	21FLA	21020031	0.41	1.24	2.23	0.41	0.33	53
BRANFORD	112WRD	02320500	0.55	0.96	2.19	0.27	0.28	83
	21FLA	21020035	0.23	1.33	2.56	0.49	0.37	37
	SRWMDT	SUW140C1	0.62	0.97	1.50	0.27	0.28	17
	DERTLH	TALDER009	0.37	1.15	2.20	0.49	0.43	25
LURAVILLE	SRWMDT	SUW130C1	0.39	0.91	2.05	0.38	0.42	17
	DERTLH	TALDER008	0.31	0.95	2.10	0.44	0.46	25
	21FLA	21020034	0.31	1.21	2.41	0.57	0.47	27
ELLAVILLE	21FLA	21020014	0.47	1.23	2.80	0.57	0.46	26
	SRWMDT	SUW100C1	0.33	0.88	1.32	0.27	0.31	17
	DERTLH	TALDER006	0.27	0.93	1.82	0.46	0.49	25
	21FLA	21010026	0.55	1.03	1.80	0.45	0.44	24
	DERTLH	TALDER005	0.25	1.02	3.76	0.72	0.71	25
	SRWMDT	SUW090C1	0.26	0.71	1.32	0.31	0.44	17
SUWANNEE	21FLA	21020015	0.26	1.75	3.79	0.89	0.51	25
	SRWMDT	SUW070C1	0.24	0.96	1.79	0.43	0.45	17
	112WRD	02315550	0.52	1.32	3.37	0.51	0.39	170
WHITE	21FLA	21020042	0.15	1.21	2.77	0.63	0.52	34
	112WRD	02315500	0.25	0.93	1.56	0.22	0.24	80
	SRWMDT	SUW040C1	0.67	1.11	1.65	0.29	0.26	17
	SRWMDT	SUW030C1	0.68	1.06	1.55	0.29	0.27	17
SR 6	112WRD	02315000	0.42	0.92	1.63	0.24	0.26	77
	SRWMDT	SUW010C1	0.35	1.15	2.45	0.42	0.37	17

All data sets at each location, for each parameter, are compared statistically using the Mann-Whitney test. In order to assess possible effects due to differences in sampling frequency, both the complete data set and monthly averaged data are compared. The monthly averaged data represent one value per month; if more than one sample was collected during the month then the data are averaged. Subsequently, if only one data point exists for the month, it represents the value for that month. The results of the Mann-Whitney test applied to SC, TP and TN at each location are summarized in Tables 3-6, 3-7 and 3-8 respectively. In each of these tables column two indicates the agencies corresponding to the two data sets compared. Columns three through five give the two-tailed probability (P) associated with the calculated test statistic for each of the data conditions evaluated; raw data, monthly averaged data, and data for the 1982-1983 period of record. As stated above, the null hypothesis (H_o) is not rejected for P values greater than 0.05. A blank in the table indicates the data are not applicable to the condition evaluated.

The comparison between agencies at each location was different for each parameter and the results are summarized below.

Specific conductivity. The time series plots for specific conductivity do not identify any long-term trends or high degree of variability. At all locations the specific conductivity data sets compared well except for SRWMDT data

Table 3-6. Mann-Whitney for Specific Conductance

LOCATION	DATA SETS COMPARED	P VALUES FOR PERIOD OF RECORD		
		RAW DATA	MONTHLY DATA	1982-83 DATA
FOWLERS	21020022 & SUW241C1	0.32		0.98
	21020022 & SUW240C1	0.005		
	SUW241C1 & SUW240C1	0.005		
FANNING	02323500 & 21020031	0.04		0.54
	21020031 & SUW160G1	0.82		
	02323500 & SUW160G1	0.65		0.72
	02323500 & SUW160C1	0.005		
BRANFORD	02320500 & 21020035	0.005	0.13	0.46
	21020035 & SUW140C1	0.005		
	21020035 & SUW140G1	0.80	0.94	0.32
	SUW140G1 & TALDER009	0.06		0.2
	02320500 & SUW140G1		0.12	0.68
LURAVILLE	02320000 & 21020034	0.68		
	21020034 & SUW130C1	0.005		
	21020034 & SUW130C1	0.64	0.64	0.32
	SUW130C1 & TALDER008			0.22
	02320000 & TALDER008	0.08		
	02320000 & SUW130C1	0.7		
	21020034 & TALDER008	0.52		0.22
	SUW130C1 & SUW130C1	0.005		
ELLAVILLE	21020014 & SUW100C1	0.005		
	21020014 & SUW100G1	0.3		
	21020014 & TALDER006	0.06		
	SUW100G1 & TALDER006	0.06		
	21010026 & SUW090C1	0.005		
	TALDER005 & SUW090C1	0.005		
	21010026 & TALDER005	0.32		
SUWANNEE	02315550 & 21020015	0.66	0.6	0.28
	02315550 & SUW070C1	0.005		
	21020015 & SUW070C1	0.005		

Table 3-6. continued

LOCATION	DATA SETS COMPARED	P VALUES FOR PERIOD OF RECORD		
		RAW DATA	MONTHLY DATA	1982-83 DATA
WHITE SPRINGS	02315500 & 21020006	0.20		0.66
	02315500 & SUW040C1	0.005		
	02315500 & SUW030C1	0.005		
	21020006 & SUW040C1	0.005		
	21020006 & SUW030C1	0.005		
	SUW040C1 & SUW030C1	0.98		
SR 6	02315000 & SUW010G1	0.06		0.34
	02315000 & SUW010C1	0.005		

TABLE 3-7. Mann-Whitney for Total Phosphorus

LOCATION	DATA SETS COMPARED	P VALUES FOR PERIOD OF RECORD		
		RAW DATA	MONTHLY DATA	1982-83 DATA
FOWLERS	21020022 & SUW240C1	0.005	0.005	
FANNING	02323500 & 21020031	0.005	0.005	0.005
	21020031 & SUW160C1	0.005		
	02323500 & SUW160C1	0.005		
BRANFORD	02320500 & 21020035	0.005		0.005
	21020035 & SUW140C1	0.005		
	02320500 & SUW140C1	0.005		
LURAVILLE	21020034 & SUW130C1	0.005	0.005	
ELLAVILLE	21020014 & SUW100C1	0.005	0.005	
	21020026 & SUW090C1	0.005		
SUWANNEE	02315550 & 21020015	0.06	0.12	0.32
	02315550 & SUW070C1	0.005		
	21020015 & SUW070C1	0.54	0.46	
WHITE	02315500 & 21020042	0.005		0.005
	02315500 & SUW030C1	0.04		
	02315500 & SUW040C1	0.52		
	21020042 & SUW040C1	0.02		
	21020042 & SUW030C1	0.02		0.32
	SUW040C1 & SUW030C1	0.005		
SR 6	02315000 & SUW010C1	0.005		

Table 3-8. Mann-Whitney for Total Nitrogen

LOCATION	DATA SETS COMPARED	P VALUES FOR PERIOD OF RECORD		
		RAW DATA	MONTHLY DATA	1982-83 DATA
FOWLERS	21020022 & SUW240C1	0.005		
FANNING	02323500 & 21020031	0.005		0.04
	21020031 & SUW205C1	0.04		
	02323500 & SUW205C1	0.005		
BRANFORD	02320500 & 21020035	0.005		0.32
	21020035 & SUW140C1	0.005		
	21020035 & TALDER009	0.26		
	02320500 & TALDER009	0.08		0.09
LURAVILLE	21020034 & SUW130C1	0.08		
	21020034 & TALDER008			0.10
	TALDER008 & SUW130C1	0.32		
ELLAVILLE	21020014 & SUW100C1	0.08		
	21020014 & TALDER006			0.05
	TALDER006 & SUW100C1	0.07		
	21020026 & SUW090C1	0.005		
	21020026 & TALDER005			0.68
	TALDER005 & SUW090C1	0.12		
SUWANNEE	02315550 & 21020015	0.01		
	02315550 & SUW070C1	0.005		
	21020015 & SUW070C1	0.005		
WHITE	02315500 & 21020042	0.02		0.02
	02315500 & SUW040C1	0.04		
	02315500 & SUW030C1	0.18		
	21020042 & SUW040C1	0.32		
	21020042 & SUW030C1	0.32		
	SUW040C1 & SUW030C1	0.32		
SR 6	02315000 & SUW010C1	0.005		

sets which consistently exhibited a higher range of values. This may be explained by the negative correlation of specific conductivity with flow (identified in the concentration-flow analysis discussed later). The SRWMDT data represent a fairly short period of record covering 1989-1990. The Suwannee River experienced a significant low flow condition during the period 1988-1990 and provides an explanation for the higher values. Because this reflects natural variability these data have been included for further analysis.

Total phosphorus. The time series plots for total phosphorus data at the locations downstream of Suwannee Springs indicate a long-term trend with increasing concentrations from early 1970 to about mid 1982, then decreasing concentrations to the latest data record of 1991. The data sets for these reaches (3 and 4) did not compare well using the Mann-Whitney test. Due to the long-term trend, differences between data sets from different time periods is expected. However, differences between data sets from the same time period can be caused by sampling location, sampling frequency and analytical variability. Analytical variability for low total phosphorus measurements is likely due to the difficulty of the lab procedures.

At and above Suwannee Springs no long-term total phosphorus trend is apparent in the time series plots. However, at Suwannee Springs the average total phosphorus concentration is an order of magnitude higher and several high

measurements were recorded in the late seventies and early eighties. The high phosphorus concentrations are related to the phosphorus mining discharges to Swift Creek. For this reach (Suwannee Springs through White Springs) the data sets compared fairly well for the same monitoring time periods. For different time periods of record, differences between the two data sets are likely due to the higher peak values during the period 1978-1983. Although analytical variability is also a possible cause, the overall higher concentrations and favorable comparison of data for similar time periods indicates analytical variability is reduced when the concentrations being measured are greater.

Although there are differences between the data sets for total phosphorus in the lower reaches (below Suwannee Springs), these data represent the best available information. The total phosphorus data sets have been combined to define the ambient water quality of the Suwannee River. To evaluate the effect of variability between data sets, the 112WRD data set at Branford is analyzed separately and the results are compared to the results of the combined data sets at the Branford location. Evaluation of the final numeric representation will take into consideration the variable characteristics of the data.

Total nitrogen. In general, the time series plots for total nitrogen data do not show any significant long-term trends. However, a slight step increase, occurring about

1979-1980, is visible for reaches 3 and 4 (below Suwannee Springs). All the data sets in reaches 2, 3, and 4 show higher peak measurements and variability during the period 1979-1983. For the same monitoring time period the total nitrogen data sets compare well. Some of the data for different time periods also compare well. Where differences between data sets covering different monitoring periods are identified, they are primarily due to the higher concentrations and variability during the early eighties. All the data sets for total nitrogen are combined for further analysis.

Flow-Concentration Relationships

The data used for the regression analysis are the combined data sets resulting from the data aggregation analysis. The functional relationships that best fit the data are summarized in Tables 3-9, 3-10 and 3-11 for specific conductivity, total phosphorus, and total nitrogen at each location. The concentration-flow data for specific conductance, total phosphorus and total nitrogen at Branford, Suwannee Springs and State Road 6 (SR6) are plotted in Figures 3-5, 3-6 and 3-7 along with the best fit regression relationship. The relationships at these three locations provide a good representation for all locations along the river. No flow data were available for Fowlers Bluff preventing concentration-flow analysis at this location.

Table 3-9. Regression Analysis Summary for Specific Conductance

LOCATION	REGRESSION RELATIONSHIP	EQUATION	STD ERR OF Y EST	R^2	DEGREES of FREEDOM	No of DATA POINTS	CONSTANT	COEFFICIENT	STE ERR of COEFF	|t|
Fowlers Bluff		no flow data available								
Fanning Springs	log-log	ln C = a + b(ln Q)	0.38	0.46	303	305	12.27	-0.76	0.0473	16.12
Branford	log-log	ln C = a + b(ln Q)	0.32	0.67	510	512	11.02	-0.68	0.0213	32
Luraville	hyp-beta6	C = a + b{1/(1 + beta*Q)}	34.53	0.83	15	17	16.38	821.95	95.49	8.61
Ellaville (below Withlacoochee)	log-log	ln C = a + b(ln Q)	0.29	0.76	158	160	10.32	-0.63	0.028	22.53
Suwannee Springs	log-log	ln C = a + b(ln Q)	0.32	0.73	120	122	7.43	-0.4	0.0223	18.08
White Springs	log-log	ln C = a + b(ln Q)	0.26	0.31	207	209	4.79	-0.11	0.0116	9.68
State Road 6	log-quad	lnC = a + b(lnQ) + C(lnQ)^2	0.22	0.04	135	138	4.37	-0.14 0.01	0.0614 0.0053	2.29 2.37

Table 3-10. Regression Analysis Summary for Total Phosphorus

LOCATION	REGRESSION RELATIONSHIP	EQUATION	STD ERR OF Y EST	R^2	DEGREES of FREEDOM	No of DATA POINTS	CONSTANT	COEFFICIENT	STE ERR of COEFF	|t|
Fowlers Bluff		no flow data available								
Fanning Springs	log-log	ln C = a + b(ln Q)	0.5	0.04	223	225	0.42	-0.22	0.07	3.1
Branford	hyp-beta4	C = a + b{1/(1 + beta*Q)}	0.16	0.04	228	230	0.14	0.22	0.07	3.13
Luraville		no flow data available								
Ellaville (below Withlacoochee)	exponential	lnC = a + bQ	0.5	0.02	41	43	0	0	0	0.92
Suwannee Springs	hyp-beta8	C = a + b{1/(1 + beta*Q)}	0.9	0.59	120	122	0.31	6.93	0.52	13.2
White Springs	hyp-beta8	C = a + b{1/(1 + beta*Q)}	0.51	0.29	154	156	-0.33	0.21	0.03	7.89
State Road 6	log-log	lnC = a + b(lnQ) + C(lnQ)^2	0.37	0.63	89	91	-0.98	-0.27	0.022	12.1

Table 3-11. Regression Analysis Summary for Total Nitrogen

LOCATION	REGRESSION RELATIONSHIP	EQUATION	STD ERR OF Y EST	R^2	DEGREES of FREEDOM	No of DATA POINTS	CONSTANT	COEFFICIENT	STE ERR of COEFF	|t|
Fowlers Bluff		no flow data available								
Fanning Springs	hyp-beta8	C=a+b{1/(1+beta*Q)}	0.36	0.01	144	146	-15.57	16.16	16.27	1.02
Branford	hyp-beta3	C=a+b{1/(1+beta*Q)}	0.4	0.07	152	154	0.04	1.23	0.36	3.45
Luraville		no flow data available								
Ellaville (below Withlacoochee)	inverse	C=a+b(1/Q)	0.51	0.14	49	51	0.77	1210.37	423.95	285
Suwannee Springs	hyp-beta8	C=a+b{1/(1+beta*Q)}	0.64	0.04	119	121	1.24	0.83	0.37	2.24
White Springs	hyp-beta8	C=a+b{1/(1+beta*Q)}	0.44	0.01	124	126	-1.21	8.29	6.26	1.33
State Road 6	log-quad	ln C=a+b(ln Q)	0.24	0.04	77	80	-0.56	0.17 -0.01	0.0924 0.0079	1.85 1.81

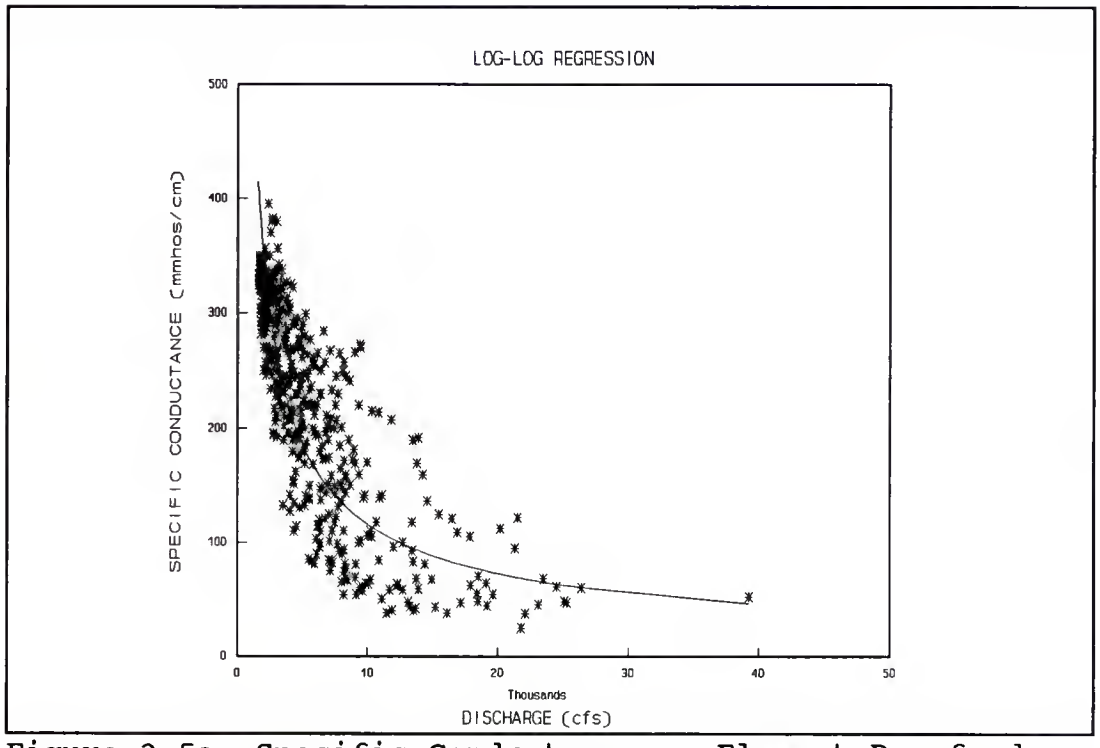

Figure 3-5a. Specific Conductance vs Flow at Branford

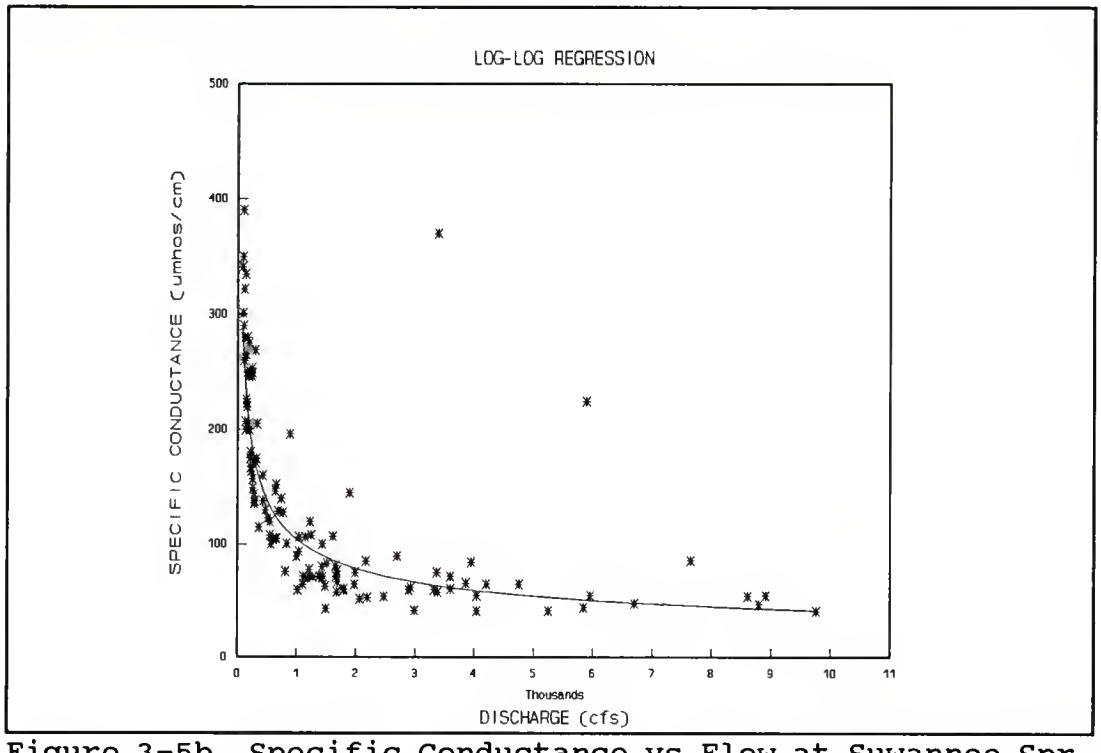

Figure 3-5b. Specific Conductance vs Flow at Suwannee Spr.

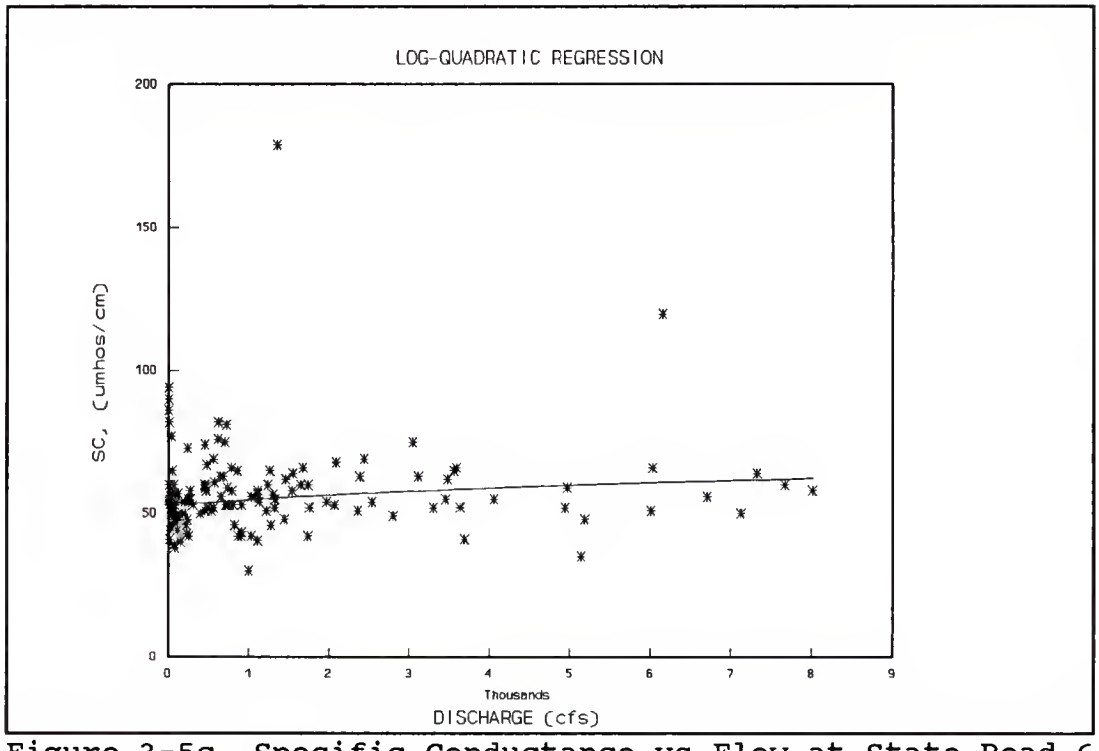

Figure 3-5c. Specific Conductance vs Flow at State Road 6

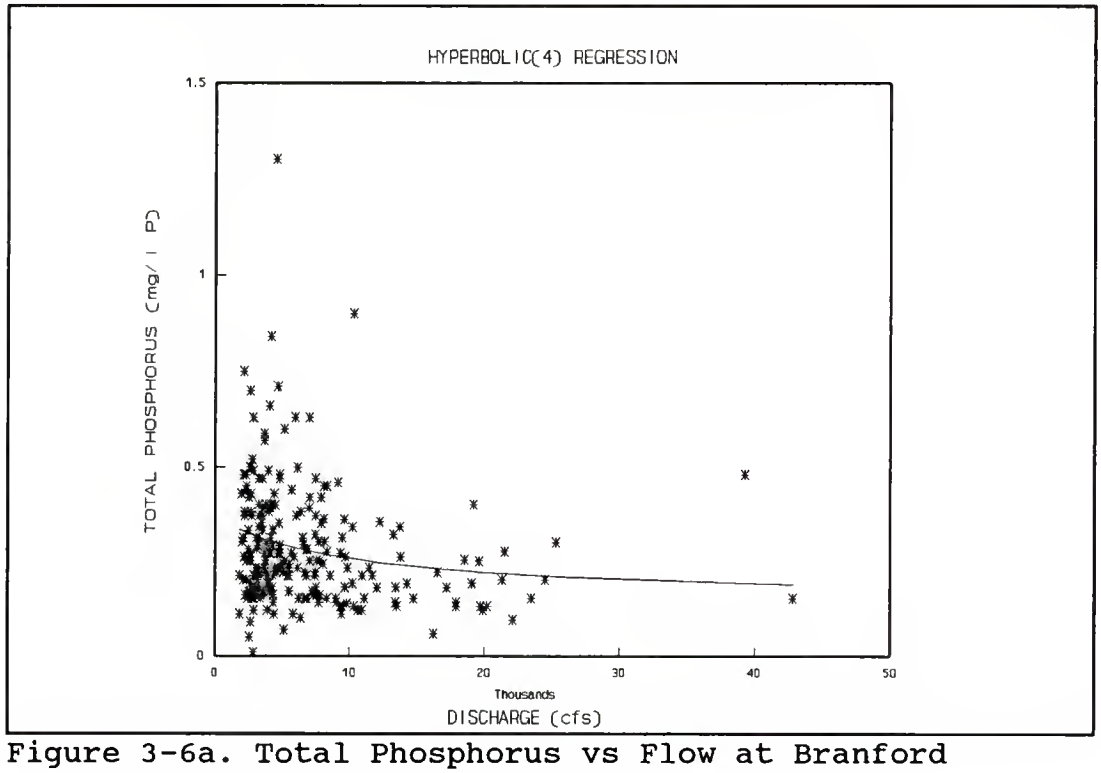

Figure 3-6a. Total Phosphorus vs Flow at Branford

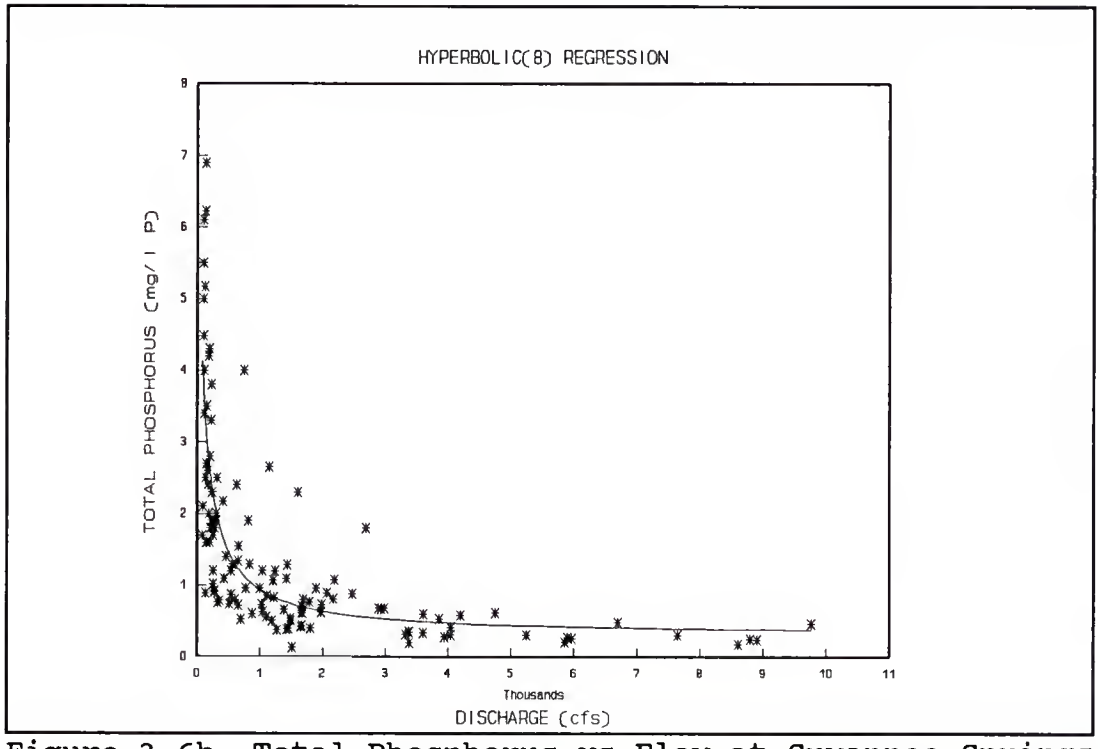

Figure 3-6b. Total Phosphorus vs Flow at Suwannee Springs

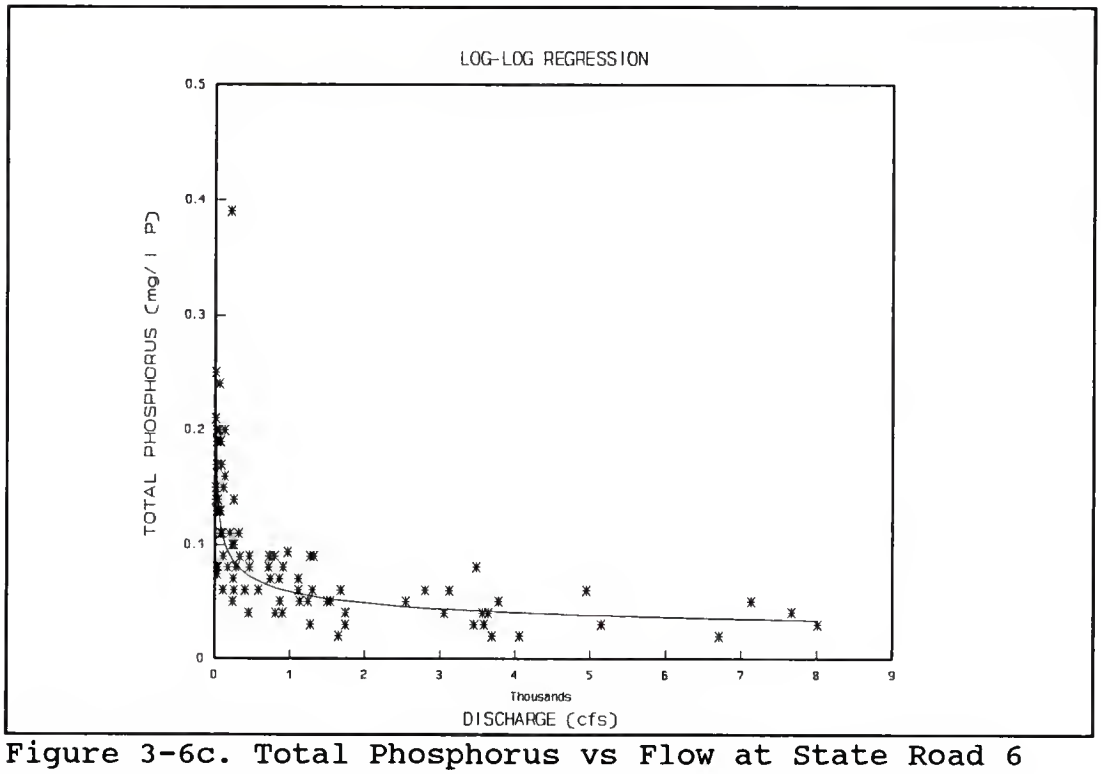

Figure 3-6c. Total Phosphorus vs Flow at State Road 6

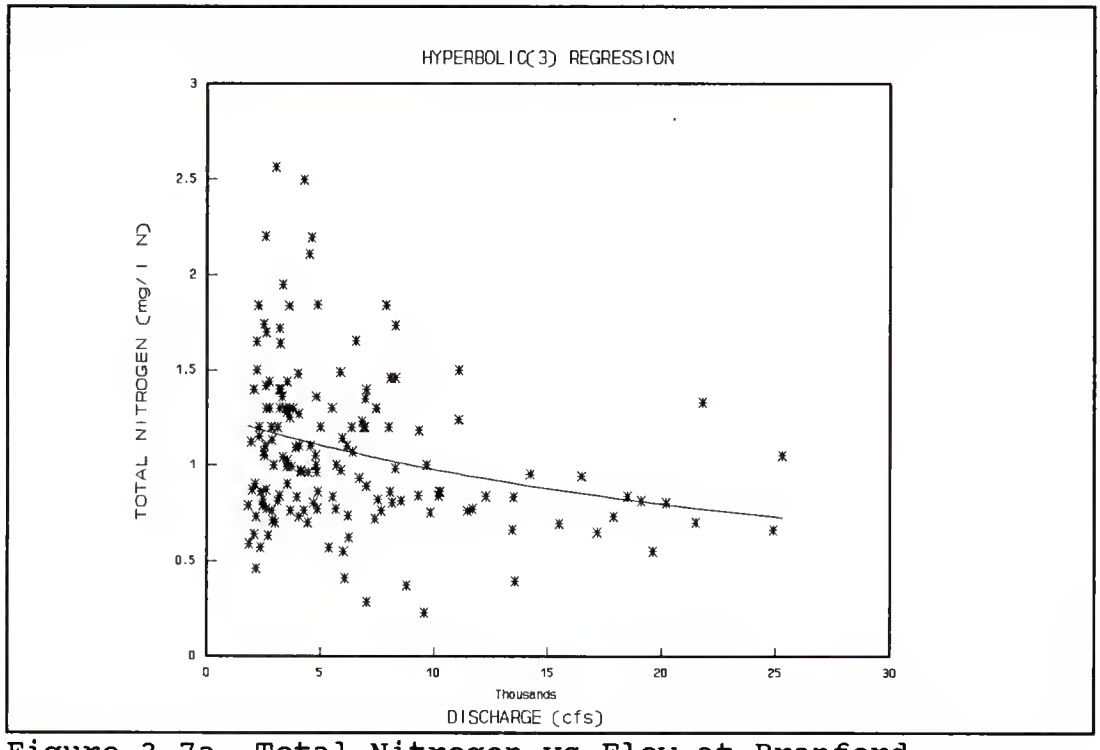

Figure 3-7a. Total Nitrogen vs Flow at Branford

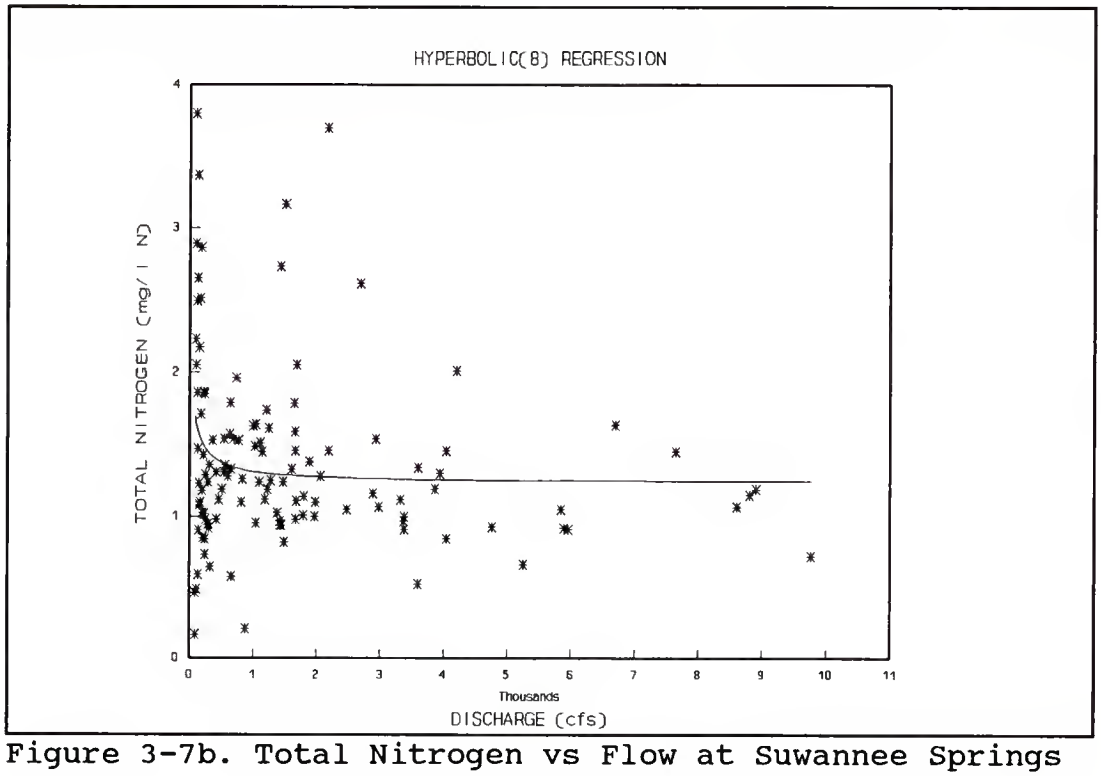

Figure 3-7b. Total Nitrogen vs Flow at Suwannee Springs

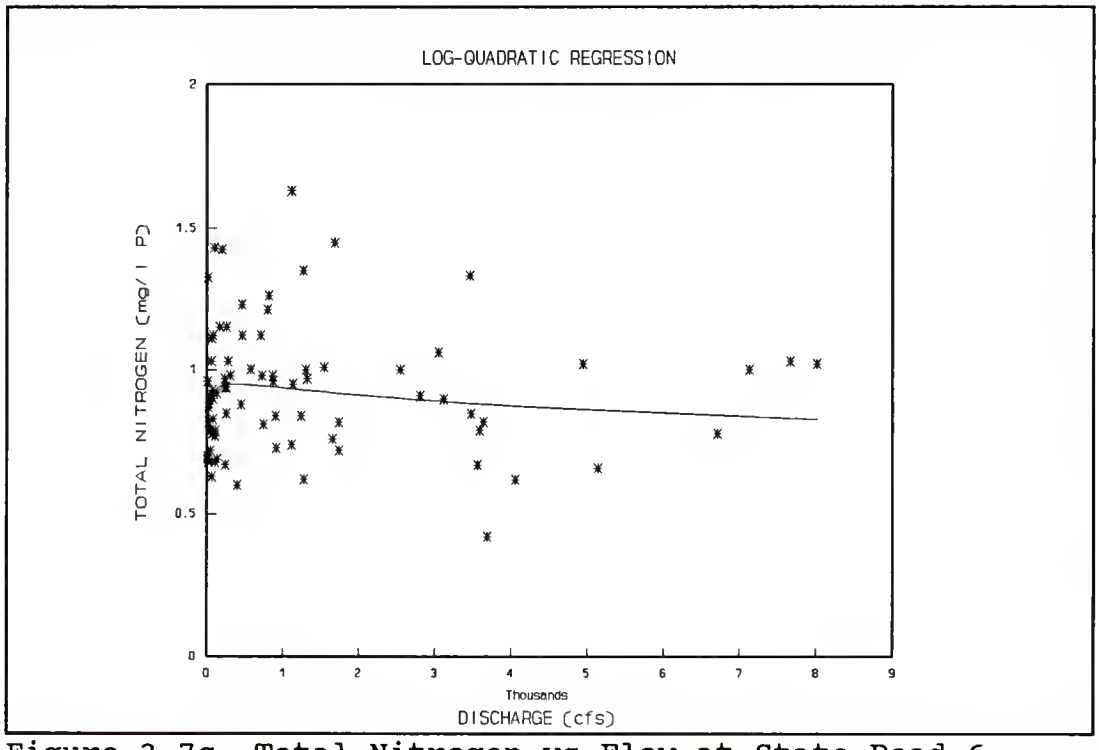

Figure 3-7c. Total Nitrogen vs Flow at State Road 6

Specific conductance. The most consistent best fit regression relationship for specific conductivity versus flow is log-log. At Luraville the best fit relationship is hyperbolic (Beta6). However, the log-log relationship was also significant (R^2 = 0.78) and could be used at this location also. At SR6 the best fit relationship is log-quadratic, but the R^2 of 0.04 shows that the correlation is insignificant. Thus, in general a log-log relationship can be used to represent specific conductivity versus flow. A closer look at the correlation coefficients reveals a pattern in the relationship from upstream to downstream. The correlation at SR6 is weak with an R^2 of 0.04. SR6 represents the upper reach of the river that is not influenced by spring flows. The remaining downstream locations are all influenced by spring flow and have significant correlation coefficients ranging from 0.83 at Luraville to 0.31 at White Springs. This relationship identifies the significance of spring inflows to the river. The relationships given in Table 3-9 are used to calculate the predicted concentration based on flow for those stations with significant correlation. The FAC values are subsequently calculated by subtracting the predicted concentration from the measured concentration. The FAC values (residuals) are used along with the raw data to evaluate possible water quality trends.

Total phosphorus. No flow data were available at Luraville for the same time period as the total phosphorus

data. Three stations show a significant correlation between total phosphorus concentration and flow; SR6, White Springs, and Suwannee Springs with R^2s of 0.63, 0.29, and 0.59 respectively. The remaining three locations have R^2s of less than or equal to 0.04. There is no consistent best fit functional relationship, probably due to the generally poor correlations overall. The three significant correlations at Suwannee Springs, White Springs, and SR6 represent strong inverse relationships. This implies that concentrations are diluted during high runoff periods and reflective of point source discharges. It is evident that Suwannee Springs is impacted by the discharge of Swift Creek. Two point source discharges potentially affect the White Springs monitoring location: 1) City of White Springs domestic wastewater treatment plant discharge, and 2) Hunter Creek approximately twenty miles upstream. However, there are no significant point source discharges above SR6. At SR6 the higher concentrations at low flows could be related to high pH and sediment releases that are diluted during high runoff.

Although the correlation is only significant at three locations, the concentration versus flow plots for total phosphorus all generally indicate a higher degree of variability at low flows. This identifies a need to consider changes in variability with season and is addressed later. FAC are calculated for SR6, White Springs, and Suwannee Springs, and are used along with raw data for trend analysis.

Raw phosphorus data are used for evaluation of possible water quality trends at Fowlers Bluff, Fanning Springs, Branford, Luraville, and Ellaville.

Total nitrogen. The relationship between total nitrogen and flow is generally not significant at any of the locations evaluated. The most significant correlation occurs at Ellaville (below Withlacoochee) with an R^2 of 0.14. The remaining correlations all have R^2s less than 0.07. However, the plots of concentration versus flow indicate higher variability during low flows, also observed in the total phosphorus data. Again, the change in variability with season is addressed later. Although the concentration-flow relationship is relatively weak, FAC values are calculated for Ellaville. Otherwise only the raw data are used to evaluate possible water quality trends in total nitrogen.

Seasonality

Seasonal analyses and interpretation of the results must take into consideration the sampling characteristics of the data base. Variability in sampling frequency will affect the variability of the statistical estimates for seasonal medians and interquartile values.

The lowest, most consistent sampling frequency for all the combined data sets evaluated is quarterly and quarterly seasonality will be used for defining ambient water quality. Three different quarterly cycles, consisting of three months

per quarter and four quarters per year, are considered. The specific quarterly cycles evaluated were given in Table 3-2.

At the locations where the parameter concentration was shown to be significantly correlated with flow, both the raw concentration data and FAC data are analyzed for seasonality. Where no significant correlation with flow was identified only the raw data sets are analyzed. The box-whiskers (BW) plots representing the most significant quarterly cycle for each parameter at Branford, Suwannee Springs and State Road 6 are presented in Figures 3-8, 3-9 and 3-10. Again, these locations provide a good representation for all locations along the river. The Kruskal-Wallis (KW) test statistics for each parameter data set and seasonal period are summarized in Tables 3-12, 3-13 and 3-14 for each location. Note at the bottom of the table are the KW test statistics for various confidence levels. Significant seasonality is indicated when the calculated KW test statistic is larger than the confidence level test statistic.

Specific conductance. The KW test statistics for specific conductance (Table 3-12) indicate two different seasonal cycles. At the two upstream locations, SR6 and White Springs, cycle three (annual quarterly cycle starting March 1) represents the strongest seasonality at a significance level of 75%. For the remaining downstream locations cycle two (annual quarterly cycle starting February 1) represents the strongest seasonality at a significance level of 95%.

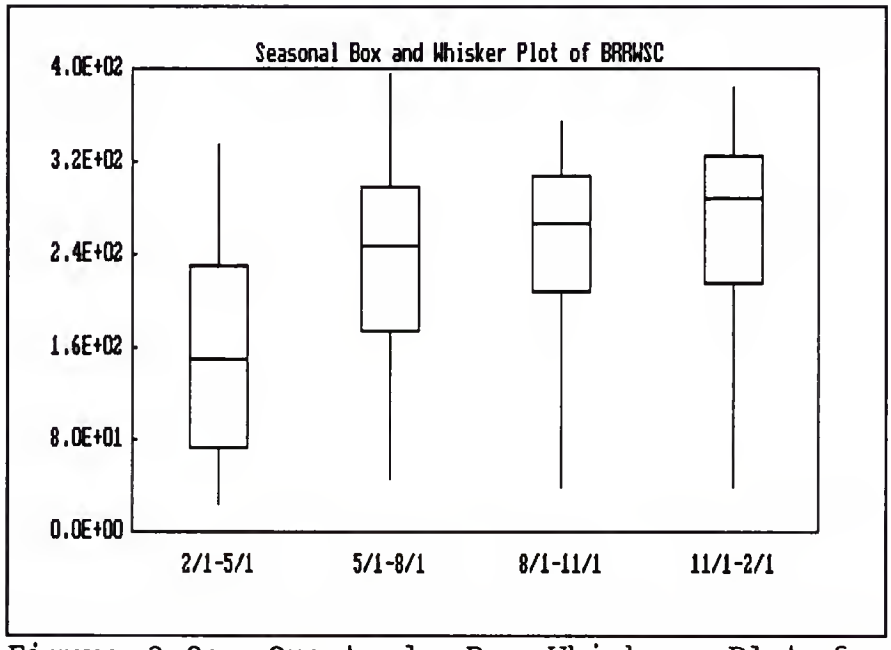

Figure 3-8a. Quarterly Box Whiskers Plot for Specific Conductance (umhos/cm) at Branford showing the median, upper and lower quartile, minimum and maximum concentrations.

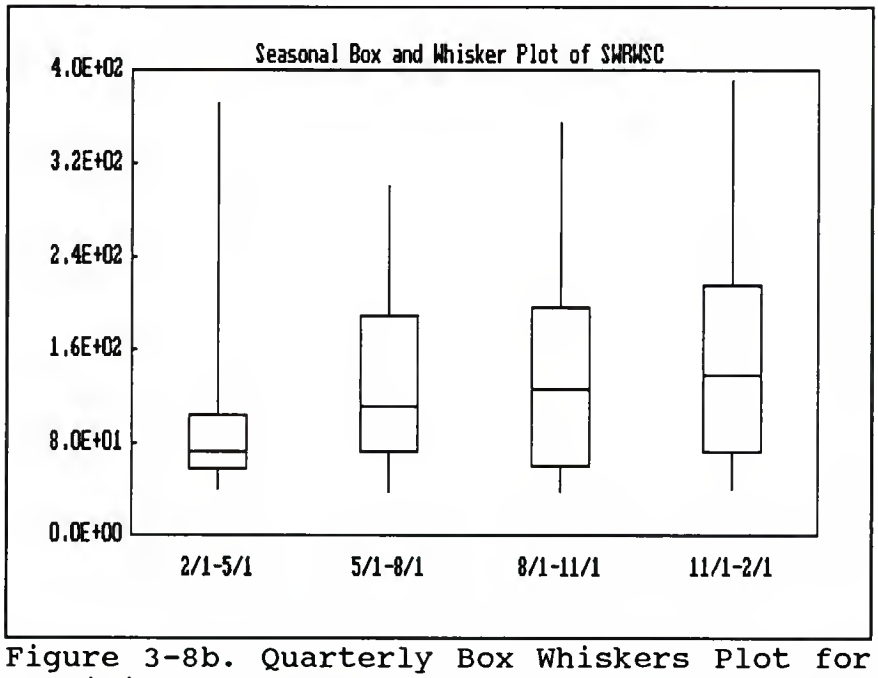

Figure 3-8b. Quarterly Box Whiskers Plot for Specific Conductance (umhos/cm) at Suwannee Springs showing the median, upper and lower quartiles, minimum and maximum concentrations.

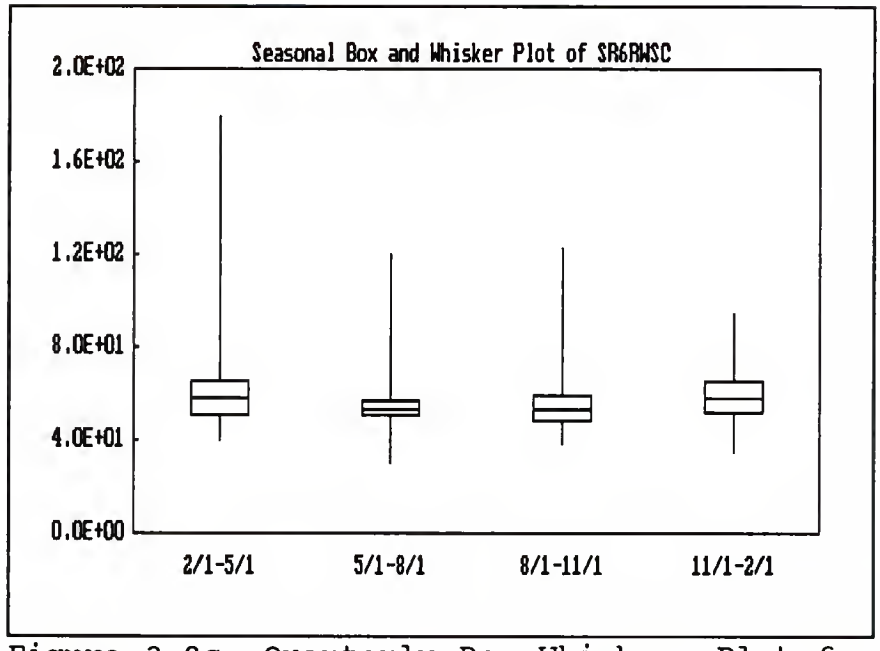

Figure 3-8c. Quarterly Box Whiskers Plot for Specific Conductance (umhos/cm) at State Road 6 showing the median, upper and lower quartiles, minimum and maximum concentrations.

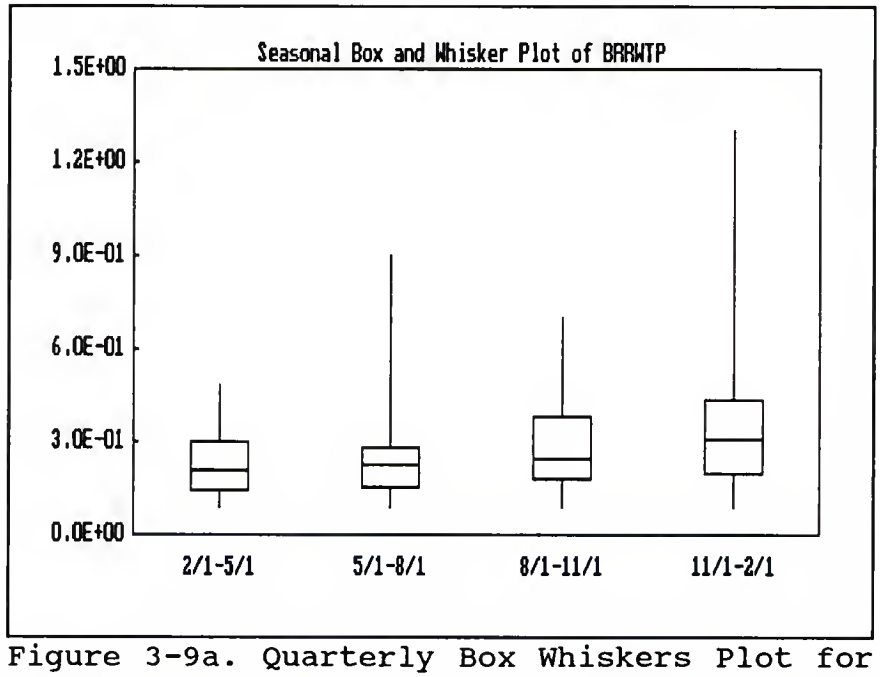

Figure 3-9a. Quarterly Box Whiskers Plot for Total Phosphorus (mg/l) at Branford showing the median, upper and lower quartiles, minimum and maximum concentrations.

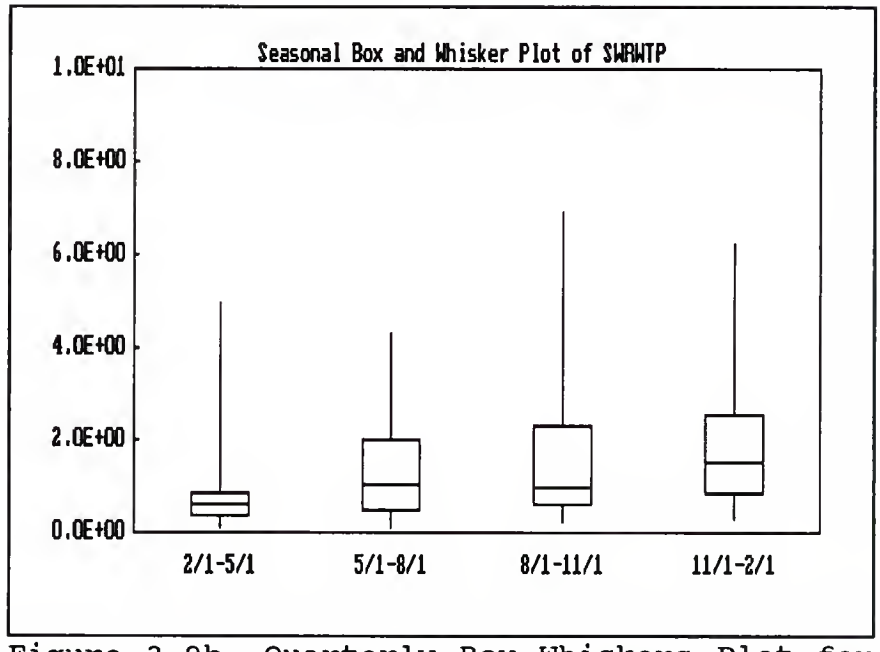

Figure 3-9b. Quarterly Box Whiskers Plot for Total Phosphorus (mg/l) at Suwannee Springs showing the median, upper and lower quartiles, minimum and maximum concentrations.

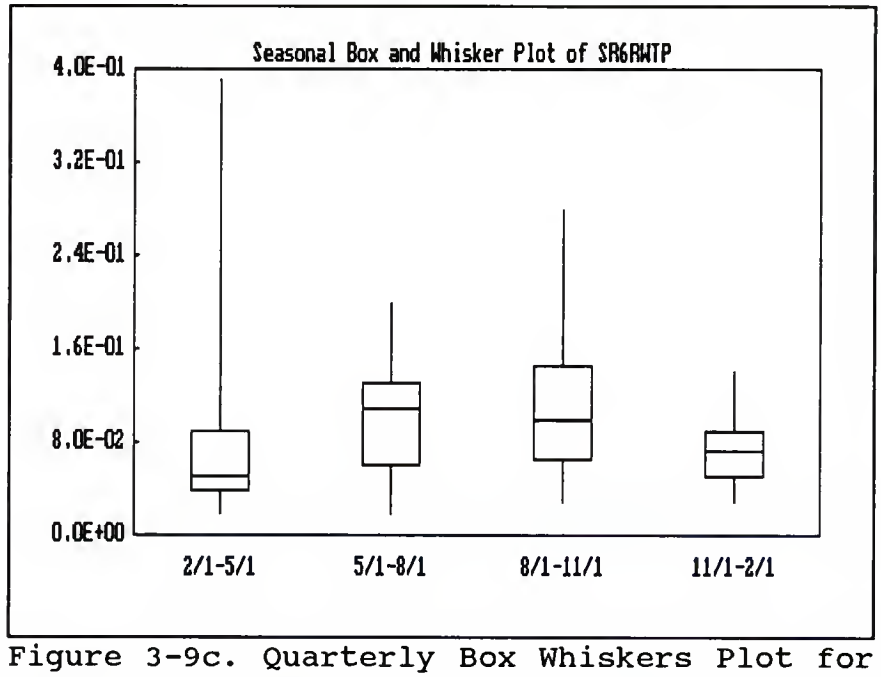

Figure 3-9c. Quarterly Box Whiskers Plot for Total Phosphorus (mg/l) at State Road 6 showing the median, upper and lower quartiles, minimum and maximum concentrations.

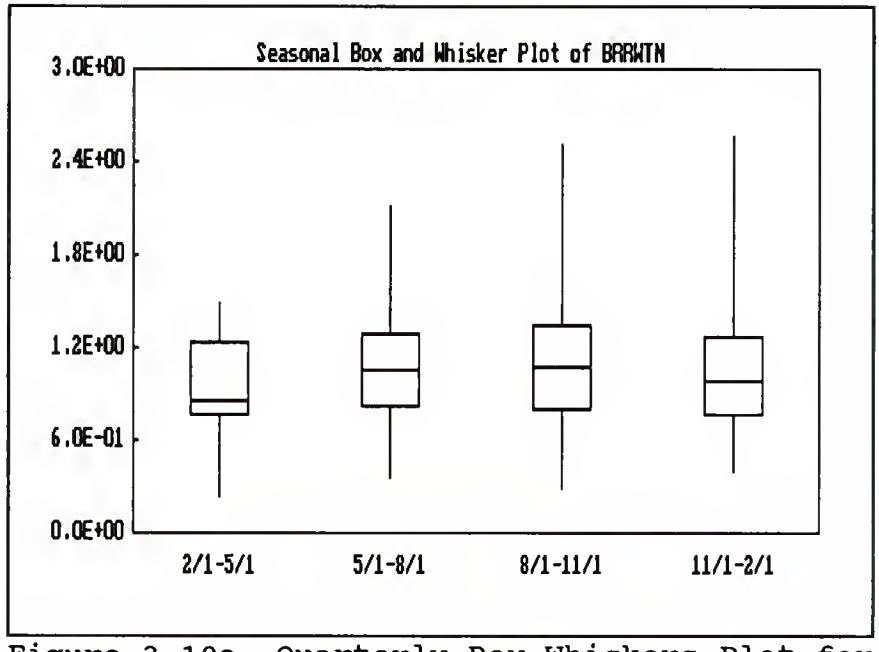

Figure 3-10a. Quarterly Box Whiskers Plot for Total Nitrogen (mg/l) at Branford showing the median, upper and lower quartiles, minimum and maximum concentrations.

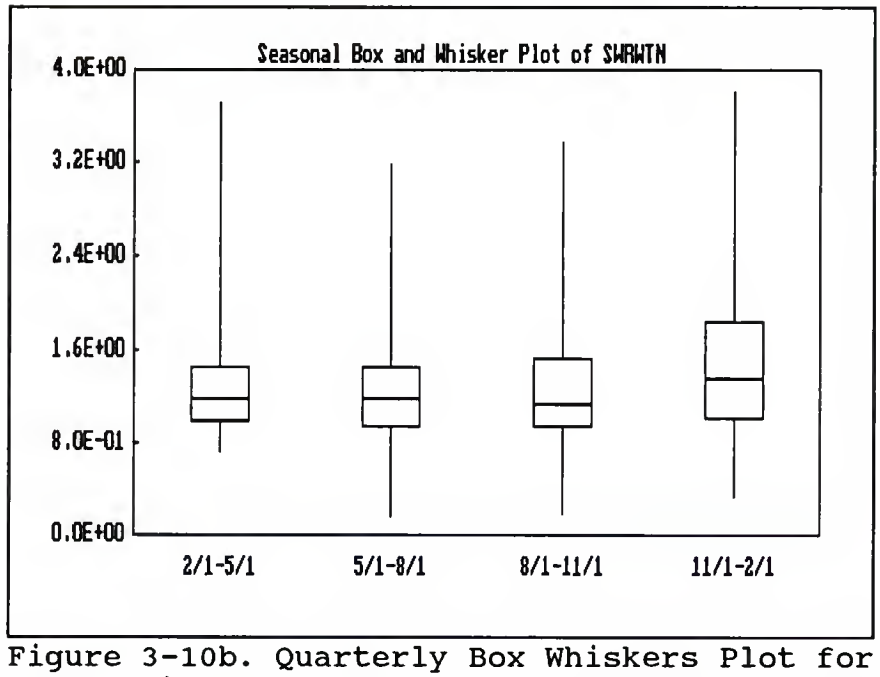

Figure 3-10b. Quarterly Box Whiskers Plot for Total Nitrogen (mg/l) at Suwannee Springs showing the median, upper and lower quartiles, minimum and maximum concentrations.

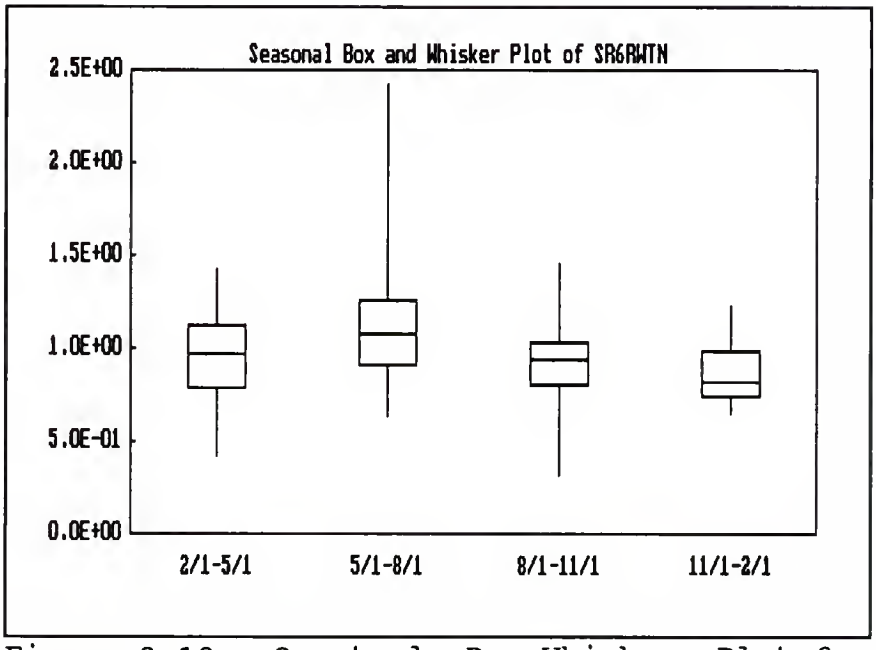

Figure 3-10c. Quarterly Box Whiskers Plot for Total Nitrogen (mg/l) at State Road 6 showing the median, upper and lower quartiles, minimum and maximum concentrations.

Table 3-12 Kruskal Wallis Seasonality Test Results for Specific Conductance

Location	Data Set	Monthly Test Statistic	Confidence Level	Cycle 1 Test Statistic	Confidence Level	Cycle 2 Test Statistic	Confidence Level	Cycle 3 Test Statistic	Confidence Level
Fowlers Bluff	RAW SC	14.7	75%	4.2	75%	5.65	75%	3.46	NS
	FAC SC	no flow data							
Fanning Springs	RAW SC	1573	95%	14.71	95%	25.17	95%	10.07	95%
	FAC SC	1340	95%	16.31	95%	8.86	95%	5.42	75%
Branford	RAW SC	3934	95%	35.00	95%	32.6	95%	22.5	95%
	FAC SC	4481	95%	29.60	95%	18.8	95%	18.10	95%
Luraville	RAW SC	42.18	95%	10.27	95%	13.37	95%	11.98	95%
	FAC SC			3.61	NS	3.77	NS	4.49	75%
Ellaville (below With)	RAW SC	43	95%	9.29	95%	11.66	95%	16.28	95%
	FAC SC	20.32	95%	7.79	90%	2.59	NS	5.38	75%
Suwannee Springs	RAW SC	16.5	75%	5.10	75%	6.7	90%	3.90	NS
	FAC SC	11.4	NS	3.67	NS	6.53	90%	7.13	90%
White Springs	RAW SC	18.0	90%	2.78	NS	3.82	NS	4.48	75%
	FAC SC	12.2	NS	2.58	NS	1.28	NS	1.92	NS
State Road 6	RAW SC	18.76	90%	2.29	NS	2.82	NS	5.06	75%
	FAC SC	no significant correlation with flow							

Theoretical test statistic for given confidence level and seasonality			
Monthly Test Statistic	Confidence Level	Quarterly Test Statistic	Confidence Level
19.68	95%	7.81	95%
17.28	90%	6.25	90%
13.7	75%	4.11	75%

Table 3-13. Kruskal Wallis Seasonality Test Results for Total Phosphorus

Location	Data Set	Monthly Test Statistic	Confidence Level	Cycle 1 Test Statistic	Confidence Level	Cycle 2 Test Statistic	Confidence Level	Cycle 3 Test Statistic	Confidence Level
Fowlers Bluff	RAW TP	5.56	NS	0.09	NS	1.05	NS	3.02	NS
	FAC TP	No flow data							
Fanning Springs	RAW TP	1114.2	95%	5.2	75%	10.97	95%	5.68	75%
	FAC TP	No correlation with flow							
Branford	RAW TP	17.8	90%	1.5	NS	6.6	90%	2.5	NS
	FAC TP	No correlation with flow							
Lureville	RAW TP	12.74	NS	3.15	NS	5.52	75%	1.47	NS
	FAC TP	No flow data							
Ellaville (below With)	RAW TP	7.99	NS	3.14	NS	4.85	75%	1.09	NS
	FAC TP	No correlation with flow							
Suwannee Springs	RAW TP	24.3	95%	8.24	95%	9.66	95%	9.48	95%
	FAC TP	15.66	NS	4.39	75%	6.07	75%	1.21	NS
White Springs	RAW TP	14.07	75%	8.18	95%	4.43	75%	3.09	NS
	FAC TP	6.89	NS	0.84	NS	3.44	NS	2.34	NS
State Road 6	RAW TP	21.50	95%	7.87	95%	6.02	75%	9.27	95%
	FAC TP	24.89	95%	18.79	95%	5.73	75%	14.78	95%

Theoretical test statistic for given confidence level and seasonality			
Monthly Test Statistic	Confidence Level	Quarterly Test Statistic	Confidence Level
19.68	95%	7.81	95%
17.28	90%	6.25	90%
13.7	75%	4.11	75%

Table 3-14 Kruskal Wallis Seasonality Test Results for Total Nitrogen

Location	Data Set	Monthly Test Statistic	Confidence Level	Cycle 1 Test Statistic	Confidence Level	Cycle 2 Test Stetistic	Confidence Level	Cycle 3 Test Statistic	Confidence Level
Fowlers Bluff	RAW TN	6.06	NS	0.96	NS	2.79	NS	0.11	NS
	FAC TN	No flow data							
Fanning Springs	RAW TN	19.03	90%	3.27	NS	1.42	NS	0.53	NS
	FAC TN	No significant correlation with flow							
Branford	RAW TN	10.9	NS	5.1	75%	3.7	NS	2.5	NS
	FAC TN	10.6	NS	3.2	NS	2.9	NS	4	NS
Luraville	RAW TN	12.71	NS	2.57	NS	2.86	NS	2.75	NS
	FAC TN	No flow data							
Ellaville (below With)	RAW TN	19.09	90%	9.23	95%	5.67	75%	6.08	75%
	FAC TN	No significant correlation with flow							
Suwannee Springs	RAW TN	7.72	NS	1.52	NS	2.14	NS	0.52	NS
	FAC TN	No significant correlation with flow							
White Springs	RAW TN	13.7	NS	3.5	NS	4.8	75%	4.43	NS
	FAC TN	No significant correlation with flow							
State Road 6	RAW TN	22.21	95%	7.78	90%	7.93	95%	11.07	95%
	FAC TN	No significant correlation with flow							

Theoretical test statistic for given confidence level and seasonality			
Monthly Test Statistic	Confidence Level	Quarterly Test Statistic	Confidence Level
19.68	95%	7.81	95%
17.28	90%	6.25	90%
13.7	75%	4.11	75%

Although Branford and Ellaville have a higher KW test statistic for cycles one and three respectively, all quarterly seasonal cycles at these two locations are highly significant. Thus, seasonality at these locations can be equally represented by either seasonal cycle. The difference in seasonal cycles between the upstream and downstream locations is logically associated with the inflow from springs. The six downstream locations are highly influenced by spring flow.

The specific conductance BW plots generally show the median is lowest in the first quarter and increases steadily to the last quarter. This reflects the inverse correlation with flow identified in the regression analysis. The difference in variance between seasons is not as consistent at each location as the difference in median. However, for the downstream locations (at and below Suwannee Springs) it is clear the variance does change with season.

Table 3-12 also gives the KS statistics for FAC data sets. Even though the data have been flow adjusted, seasonality is still present. Of the six locations with FAC data only one does not indicate seasonality at or above the 75% significance level. Four of the six locations show seasonality at a significance level greater than or equal to 90%. It is apparent that seasonality still remains within the data after flow adjustment. Cycle three is again the most significant seasonal cycle for the two upstream locations. At the downstream locations, cycle one is the most significant

quarterly season for the FAC data. Thus, if the data are flow adjusted different seasonality must be considered for the locations downstream of White Springs.

Total phosphorus. The KW test results for total phosphorus also show a difference in seasonal cycles from upstream to downstream, as was indicted in the specific conductance data. Again, the two upstream locations can be separated from the six downstream locations. The most significant quarterly season for the upstream locations is cycle one (annual cycle starting January 1). The most significant quarterly seasonality for the downstream locations is cycle two; the same as for specific conductance. The seasonality is not as strong for the total phosphorus data as it was for the specific conductance data. All locations, except Fowlers Bluff, indicate seasonality at or above the 75% significance level.

The BW plots for total phosphorus show that the median concentration tends to increase from the first quarter to the last quarter or remains fairly constant. The general pattern for variability is to increase from the first quarter to the second quarter and then remain somewhat constant. Variability between seasons at Ellaville is opposite to the other locations in that it is higher during the first two quarters. This might be due to the influence of the Withlacoochee. In general, it appears that higher concentrations and variability

occur during the low flow seasons. This was also indicated in the concentration versus flow plots.

Only one downstream location, Suwannee Springs, has FAC total phosphorus data. At this location seasonality is indicated in the FAC data at a significance level of 75%. Both upstream locations have FAC total phosphorus data. Seasonality of the FAC data at White Springs is not significant, while at SR6 seasonality is indicated at the 95% significance level. The most significant seasonal cycles for the FAC data are the same as for the raw (unadjusted) total phosphorus data.

Total nitrogen. As indicated in Table 3-14, the total nitrogen data generally do not exhibit significant seasonality. Four of the eight locations show no significant seasonality and two indicate seasonality only at a significance level of 75%. Ellaville and State Road 6 do indicate seasonality at the 95% significance level. Although most of the analyses are insignificant, the KW test statistic is generally higher for seasonal cycle two.

From the BW plots for the unadjusted total nitrogen data, it is difficult to assess any patterns which reflect the insignificance of the KW tests for seasonality. There appears to be more variability in the last two quarters which is similar to the total phosphorus data. Again, this is associated with the normal low flow period.

Summary. The seasonal analysis indicates a significant seasonal change taking place generally between the last and first quarters of the year. This somewhat abrupt difference is associated with the start of the annual wet period. After this initial significant difference, the changes through the rest of the year are more gradual. This leads to a fairly clear definition of the change from dry to wet seasons in the first part of the year. However, seasonal differences throughout the rest of the year are less obvious and difficult to define. Along with differences in seasonal medians, the BW plots indicate differences in variance between seasons. Thus, deseasonalization of the data will consider both seasonal means and variance.

The quarterly seasonal analysis identified a different seasonal pattern for two reaches along the river. The downstream locations: Fowlers Bluff, Fanning Springs, Branford, Luraville, Ellaville and Suwannee Springs all exhibit a consistent quarterly seasonal cycle starting February 1 (cycle 2) for all parameters. In contrast, the upstream locations, White Springs and State Road 6, have quarterly seasonality that varies with each parameter. At these two upstream locations, specific conductance exhibits a cycle 3 seasonality, total phosphorus exhibits a cycle 1 seasonality, and total nitrogen exhibits a cycle 2 seasonality. It should be noted that overall total nitrogen

seasonality was not significant and can be represented by any of the three quarterly seasonal cycles.

For the upstream locations, the question arises as to whether to represent each parameter with a different seasonality or use a uniform seasonality for all monitoring locations. Considering that several parameters will eventually be evaluated and monitored using the methodology presented in this study, separate seasonality for each parameter will require a significant effort to track and maintain appropriate records for each condition. Use of uniform seasonality will enable an approach, applicable to all locations along the river. Additionally, a uniform seasonality will enable direct comparisons between different locations and possibly permit combining of different locations in the future. In light of these considerations, a quarterly seasonal cycle starting February 1 (cycle 2) is selected to represent the three parameters at each location.

A second question raised within the seasonal analysis deals with seasonality of FAC data and seasonality of raw unadjusted data. Flow data are not available at all locations. Specifically, long-term flow records are only available at six out of a total twenty-four monitoring locations along the river. At locations where flow data are not available, concentration-flow relationships cannot be taken into consideration directly. This leads to some differences in the approach depending on the location. The seasonal

analysis shows that seasonality is still present and significant for most of the FAC data. Subsequently, the FAC data still require a deseasonalization step as is also required for the raw unadjusted data. Initially we realize that flow in itself is highly seasonal. If it can be shown that deseasonalization can account sufficiently for concentration-flow relationships, then the flow adjustment step is not necessary. This will enable a simple deseasonalization step applicable to all locations. To evaluate how well deseasonalization can account for the concentration-flow relationship, the water quality criteria results for data that are flow adjusted and deseasonalized will be compared with unadjusted deseasonalized data.

At each location seasonality will be described by a quarterly mean and standard deviation for each parameter. The mean and standard deviation are calculated for each seasonal period and are shown in Tables 3-15, 3-16 and 3-17.

Trend Analysis

A PC computer model (SEAKEN) for the seasonal Kendall trend test and the slope estimator was obtained from James Slack, U.S. Geological Survey, Menlo Park, California. This model incorporates changes to the SAS Kendall Tau procedures to account for seasonality and also includes the slope estimator. This model represents the most current methodologies for evaluating water quality trends. A water

Table 3-15. Seasonal Characteristics For Specific Conductance

Quarter	Period	MONITORING LOCATION															
		Fowlers Bluff		Fanning Springs		Branford		Luraville		Ellaville		Suwannee Springs		White Springs		State Road 6	
		mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD
1	Feb-Apr	173	78.2	164	89.2	159	86.9	122	81.4	111	70.8	94	64.1	59	18.3	61	21.7
2	May-Jul	224	87.5	251	82.3	236	80	209	73	189	66.1	137	75.6	58	19.3	55	15.6
3	Aug-Oc	268	59.3	249	78.8	251	69.6	228	67.4	224	67.9	142	92.1	64	26.8	57	13.7
4	Nov-Ja	281	68	257	80.1	258	89.4	209	90.6	200	93.8	160	96.9	69	25.2	60	13.7

Table 3-16. Seasonal Characteristics For Total Phosphorus

Quarter	Period	MONITORING LOCATION															
		Fowlers Bluff		Fanning Springs		Branford		Luraville		Ellaville		Suwannee Springs		White Springs		State Road 6	
		mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD
1	Feb-Apr	0.13	0.06	0.13	0.09	0.12	0.08	0.19	0.17	0.2	0.07	0.84	0.92	0.21	0.17	0.07	0.07
2	May-Jul	0.09	0.06	0.13	0.08	0.14	0.12	0.17	0.12	0.25	0.18	1.28	0.98	0.26	0.14	0.11	0.06
3	Aug-Oct	0.17	0.13	0.17	0.15	0.18	0.11	0.22	0.12	0.25	0.08	1.58	1.39	0.23	0.14	0.12	0.07
4	Nov-Jan	0.13	0.07	0.19	0.11	0.22	0.19	0.41	0.26	0.36	0.25	2.14	1.71	0.21	0.15	0.08	0.04

Table 3-17. Seasonal Characteristics For Total Nitrogen

Quarter	Period	MONITORING LOCATION															
		Fowlers Bluff		Fanning Springs		Brenford		Luraville		Ellaville		Suwannee Springs		White Springs		State Road 6	
		mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD
1	Feb-Apr	0.95	0.3	1.06	0.29	1.07	0.27	0.91	0.5	0.95	0.47	1.38	0.61	1.07	0.4	0.94	0.24
2	May-Jul	0.77	0.24	1.04	0.32	1.15	0.35	0.82	0.34	0.8	0.38	1.29	0.62	1.09	0.4	1.15	0.4
3	Aug-Oct	0.8	0.35	1.15	0.32	1.26	0.45	0.92	0.56	0.89	0.47	1.27	0.64	1.07	0.43	0.92	0.22
4	Nov-Jan	0.99	0.53	1.17	0.4	1.18	0.4	0.97	0.59	0.87	0.64	1.48	0.74	0.84	0.34	0.87	0.17

quality statistics program (WQSTAT II) developed at Colorado State University was used to conduct the medians analysis for step trends. Additionally, WQSTAT II includes the seasonal Kendall trend test and slope estimator and is used to compare with the results of the USGS model.

Both of the models use the median value within each seasonal time period to obtain one value for each season. For quarterly seasonality, all the data points within each quarter are evaluated to determine the median for that quarter. This generates a time series of seasonal median values for the period of record. Seasons without data are handled as missing. The trend analysis will be affected by the variability of the sampling frequency depending on the seasonal period chosen. For comparison, trend analysis was conducted for both monthly and quarterly seasonality. No significant differences were apparent and the quarterly trend analysis results are presented below. Initially, the time series plots are examined to determine whether to evaluate for a step trend or monotonic trend.

Specific conductance. From the time series plots there initially appears to be no long-term trend and no difference in the time series pattern from upstream to downstream. The specific conductance data are fairly continuous at each location except Fowlers Bluff. The SC data at Fowlers Bluff only covers two time periods 1982-1983 and 1989-1990. Therefore, only a medians analysis is conducted on the Fowlers

Bluff data. The other locations are evaluated using both median analysis (step trend) and monotonic trend analysis. However, because the data records are continuous the monotonic trend analysis is more meaningful. The results for the medians and monotonic trend analyses for specific conductance are given in Tables 3-18 and 3-19, respectively.

The medians analysis comparing the early data record (before March 1979) with the later data record (after March 1979) indicates no significant differences at Fanning Springs, Luraville, Ellaville and Suwannee Springs. At Branford, the medians comparison is significant, indicating higher concentrations in the later period and the difference (22.2 umhos/cm for FAC data) is approximately 10% of the mean and 20% of the standard deviation. At White Springs and SR6, the medians analysis also shows a higher median for the later period. The difference in medians between the two periods is again on the order of 10% to 15% of the mean concentration.

At Fanning Springs, Branford, Luraville, Suwannee Springs and White Springs no significant (>=95%) monotonic trends are indicated for the complete period of record or the period of record since the baseline year. At SR6, the complete record shows a significant trend of .93 umhos/cm per year. The period since the baseline year has no significant trend. At Ellaville, both the complete period of record and the period since the baseline year have significant trends of about 5 umhos/cm per year.

Table 3-18. Summary of Median Analyses on Specific Conductance

Location	RAW (umhos/cm)	Difference in Medians (UNITS)	Absolute Value of Test Statistic	Significance Confidence Level	FAC (umhos/cm)	Difference in Medians (UNITS)	Absolute Value of Test Statistic	Significance Confidence Level
Fowlers Bluff	1981-83 to 1988-90	77.5	3.017	95%	no flow data	-	-	-
Fanning Springs	1963-79 to 1979-91	37.89	2.46	95%	1963-79 to 1979-91	1.727	0.032	NS
Branford	-	25.909	1.856	90%	1954-78 to 1979-90	22.252	1.999	95%
	-	30.375	2.005	95%	1966-78 to 1979-90	20.09	1.809	90%
Luraville	1977-79 to 1979-91	-6	0.579	NS	1977-79 to 1979-81	-3.216	1.149	NS
Ellaville	1977-79 to 1979-91	11	0.766	NS	1977-79 to 1979-90	5.862	0.428	NS
Suwannee Springs	1956-79 to 1979-90	29.5	2.62	95%	1974-79 to 1979-90	1.607	0.304	NS
White Springs	1966-79 to 1979-91	14.667	4.336	95%	1966-79 to 1979-91	11.899	3.791	95%
State Road 6	1963-79 to 1979-91	10	3.365	95%	no significant correlation	-	-	-

Table 3-19 Summary of Monotonic Trend Analyses on Specific Conductance

Location	(Raw umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)	(FAC umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)
Fowlers Bluff	1981 to 1990	0.1032	90%	7.143	no flow data	-	-	-
	1981 to 1983	0.2453	75%	-27.750	no flow data	-	-	-
	1989 to 1990	>.999	<.001%	-37.500	no flow data	-	-	-
Fanning Springs	1963 to 1990	0.0268	97%	3.266	1963 to 1990	0.1157	88%	1.168
	1963 to 1979	0.2239	78%	-3.750	1963 to 1979	0.8131	19%	-0.261
	1979 to 1990	0.0536	95%	6.536	1979 to 1990	0.1026	90%	3.105
Branford	-	0.08	92%	-7.5	1954 to 1978	0.898	10%	0.163
	-	0.004	>99%	8.417	1979 to 1990	0.299	70%	1.919
	-	0.02	98%	3.09	1954 to 1990	0.057	94%	0.980
Luraville	1966 to 1991	0.5473	45%	1.885	1977 to 1981	0.2888	71%	-7.962
	1966 to 1979	0.8374	16%	-1.000	1977 to 1979	>.999	<.001%	-11.490
	1979 to 1991	0.0927	91%	7.667	1979 to 1981	>.999	<.001%	-4.433
Ellaville	1977 to 1991	0.0305	97%	7.325	1977 to 1990	0.0032	>.99%	5.038
	1977 to 1979	>.999	<.001%	92.000	1977 to 1979	0.2482	75%	43.180
	1979 to 1991	0.0299	97%	9.500	1979 to 1991	0.0107	>.99%	5.334
Suwannee Springs	1958 to 1990	0.0027	>99.9%	3.077	1974 to 1990	0.1939	81%	1.394
	1956 to 1979	0.5319	47%	1.292	1974 to 1979	0.6734	33%	5.525
	1979 to 1990	0.0132	99%	8.571	1979 to 1990	0.0906	91%	2.271
White Springs	1966 to 1990	0.0004	>99.9%	1.286	1966 to 1990	0.0106	99%	0.843
	1966 to 1979	0.3324	67%	0.714	1966 to 1979	0.7066	29%	0.318
	1979 to 1990	0.1502	85%	1.500	1979 to 1990	0.8360	16%	-0.119
State Road 6	1965 to 1991	0.0033	>99.9%	0.931	no flow correlation	-	-	-
	1965 to 1979	0.7384	26%	0.500	no flow correlation	-	-	-
	1979 to 1991	0.3315	67%	0.500	no flow correlation	-	-	-

In general, there is no strong long-term trend in specific conductance. Where trend is significant, the estimated magnitude of the trend is relatively small. There is not sufficient justification for detrending the specific conductance data. Therefore, the entire period of record will be used to represent the ambient water quality characteristics for specific conductance.

Total phosphorus. The monitoring locations evaluated can be placed into three groups with regard to trends in phosphorus. The first group consists of the five downstream stations: Fowlers Bluff, Fanning Springs, Branford, Luraville, and Ellaville. Suwannee Springs is considered individually and White Springs and SR6 make up the third group. Results of the medians and monotonic trend analyses for total phosphorus are summarized in Tables 3-20 and 3-21, respectively.

1) Fowlers Bluff to Ellaville

At Fanning Springs and Branford the total phosphorus records are continuous from 1971 to 1991. Fowlers Bluff, Luraville, and Ellaville all have discontinuous records covering two different time periods: 1981-1982 and 1989-1991. Although, Luraville does have a few infrequent measurements covering the period 1973-1981 which provides some data for the earlier time period.

The continuous time series plots indicate a gradually increasing trend starting about 1971, continuing up through about 1981-1982 where the trend reverses, decreasing to the

Table 3-20 Summary of Median Analyses on Total Phosphorus

Location	(RAW umhos/cm)	Difference in Medians (UNITS)	Absolute Value of Test Statistic	Significance Confidence Level	(FAC umhos/cm)	Difference in Medians (UNITS)	Absolute Value of Test Statistic	Significance Confidence Level
Fowlers Bluff	1981-83 to 1989-90	-0.221	3.464	95%	no flow data	-	-	-
Fanning Springs	1970-79 to 1979-91	0.055	3.21	95%				
	1970-82 to 1982-90	0.008	0.523	NS				
Branford	1971-79 to 1979-91	0.045	2.202	95%				
	1971-82 to 1982-91	-0.02	0.584	NS				
Luraville	1973-79 to 1979-91	0.127	2.277	95%	no significant correlation			
	1973-82 to 1982-91	-0.03	0.363	NS				
Ellaville	1981-84 to 1989-91	-0.17	3.184	95%	no significant correlation			
Suwannee Springs	1971-79 to 1979-90	0.217	1.218	NS	1974-79 to 1979-90	0.03	0.183	NS
	1971-82 to 1982-90	0.12	0.891	NS	1974-82 to 1982-90	0.09	0.302	NS
White Springs	1970-79 to 1979-90	0.08	4.68	95%	1970-79 to 1979-90	0.015	-1.8	90%
	1970-82 to 1982-90	0.06	3.207	95%	1970-82 to 1982-90	0.014	1.55	80%
State Road 6	1975-79 to 1979-91	0.03	1.924	90%	1975-79 to 1979-91	0.016	1.924	90%
	1975-82 to 1982-91	0.027	2.222	95%	1975-82 to 1982-91	0.016	2.541	95%

Table 3-21 Summary of Monotonic Trend Analyses on Total Phosphorus

Location	(raw umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)	(FAC umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)
Fowlers Bluff	1981 to 1990	0.0004	>99.9%	-0.031	no flow data	-	-	-
	1981 to 1983	0.2453	75%	-0.037	no flow data	-	-	-
	1989 to 1990	0.6171	38%	-0.078	no flow data	-	-	-
Fanning Springs	1970 to 1990	0.0726	93%	0.003	no significant correlation	-	-	-
	1970 to 1979	0.0076	99%	0.012	no significant correlation	-	-	-
	1979 to 1990	0.013	99%	-0.009	no significant correlation	-	-	-
	1970 to 1982	0.0026	>99.9%	0.013	no significant correlation	-	-	-
	1982 to 1990	0.015	99%	-0.015	no significant correlation	-	-	-
Branford	1971 to 1978	0.0116	99%	0.025	no significant correlation	-	-	-
	1978 to 1991	0.0069	99%	-0.013	no significant correlation	-	-	-
	1971 to 1982	0.0005	>99.9%	0.023	no significant correlation	-	-	-
	1982 to 1991	0.0134	99%	-0.022	no significant correlation	-	-	-
	1971 to 1991	0.6434	36%	0.001	no significant correlation	-	-	-
Luraville	1973 to 1982	0.1904	81%	0.041	no flow data	-	-	-
	1982 to 1990	0.0051	99%	-0.025	no flow data	-	-	-
	1973 to 1979	>.99	<.001%	-0.013	no flow data	-	-	-
	1979 to 1991	0.0021	>99.9%	-0.025	no flow data	-	-	-

Table 3-21. continued

Location	(raw umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)	(FAC umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)
Ellaville	1981 to 1991	0.0475	95%	-0.020	no significant correlation	-	-	-
	1981 to 1982	>.99	<.001%	0.040	no significant correlation	-	-	-
	1981 to 1983	0.3261	67%	-0.058	no significant correlation	-	-	-
	1989 to 1991	>.99	<.001%	0.013	no significant correlation	-	-	-
Suwannee Springs	1970 to 1990	0.0467	95%	0.029	1974 to 1990	0.0051	99%	-0.051
	1970 to 1979	0.0083	99%	0.161	1974 to 1979	0.0076	99%	0.305
	1979 to 1990	0.6040	40%	0.029	1979 to 1990	0.0096	99%	-0.059
	1970 to 1982	0.0092	99%	0.072	1974 to 1982	0.6987	30%	0.014
	1982 to 1990	0.1948	81%	0.066	1982 to 1990	0.0002	>99%	-0.130
White Springs	1970 to 1990	0.0018	100%	0.006	1970 to 1990	0.0167	98%	0.004
	1970 to 1979	0.8125	<.001%	0	1970 to 1979	0.9387	6%	0
	1979 to 1990	0.5725	43%	0.003	1979 to 1990	0.7928	21%	-0.001
	1970 to 1982	0.0236	98%	0.008	1970 to 1982	0.0235	98%	0.007
	1982 to 1990	0.6504	35%	-0.004	1982 to 1990	0.043	96%	-0.017
State Road 6	1975 to 1991	0.0028	>99%	0.004	1975 to 1990	0.0144	99%	0.002
	1975 to 1979	0.1283	87%	0.020	1975 to 1979	0.3141	69%	0.002
	1979 to 1991	0.0233	98%	0.006	1979 to 1990	0.1414	86%	0.002
	1975 to 1982	0.0057	99%	0.010	1975 to 1982	0.4088	59%	0.002
	1982 to 1991	0.0021	>99%	0.010	1982 to 1990	0.6058	39%	0.002

current time period. Thus, two monotonic periods are identified, one indicating increasing trend and the other a decreasing trend. This requires separation of the data into two time periods for analysis of monotonic trends. A closer examination of the time series plot and the actual data values indicates the maximum concentration period occurs about the middle of 1982. Taking into consideration the baseline year, four time periods are evaluated: 1) 1971-1979, 2) 1979-1990, 3) 1971-mid 1982, and 4) mid 1982-1990. These periods were compared using medians analysis and evaluated individually for monotonic trends.

Medians comparison at all five locations shows that the total phosphorus concentration prior to the baseline year (1973-1978) is less than the concentration following the baseline year (1979-1990). This is somewhat expected because the maximum concentrations occur in 1982. Comparison of the records before and after mid 1982 show no significant difference in median concentrations. This tends to indicate that the increase in concentration from 1971 to mid 1982 is balanced by the decrease in concentration from mid 1982 to 1990.

Monotonic trend analysis of the complete continuous records (1971-1990) shows no significant trend. However, analysis of the period up to mid 1982 and after mid 1982 shows significant increasing and decreasing trends, respectively.

Additionally, the magnitude of the increasing trend is relatively equal to the decreasing trend.

The trend analyses indicate that the most recent data are similar in concentration to the earliest period of record. Subsequently, both represent the best water quality with regard to the baseline year. To establish the ambient water quality, the data for the continuous records (Fanning Springs and Branford) are adjusted to the current time period by detrending from mid 1982 to 1991 using the decreasing trend slope estimates and the data from 1971 to mid 1982 are also detrended back to 1971. The total phosphorus data at Fowlers Bluff, Luraville, and Ellaville are detrended by subtracting the difference in means from the early time period (1982-1983). It should be pointed out that adjustment of the data assumes the trends in total phosphorus concentration are due to anthropogenic impacts in the upper basin.

2) Suwannee Springs

At Suwannee Springs, the total phosphorus data are fairly continuous over the period of record 1971-1991. The primary reason this location is evaluated individually is because the average concentration is an order of magnitude higher than any of the other stations. The long-term total phosphorus trend apparent in the downstream stations is no longer visible and is either masked by the higher concentrations or caused by some impact located below Suwannee Springs. Although there is no visible trend, several peak values occur during the late

seventies and early eighties. These peaks are two to six times the average concentration at this location.

Both the medians analysis and monotonic trend analysis do not indicate any significant trends. The higher concentrations at this location reflect the permitted discharges of OXY Chemical to Swift Creek. At the present time, the complete data set is used to define total phosphorus ambient water quality at this location and will reflect the permitted discharge. However, consideration should be given to removing the peak values measured during the late seventies and early eighties. The data record since 1983 does not reflect these high concentrations. Justification for removal of these high concentration values must take into consideration the specific requirements of the permitted discharge(s) upstream of this reach.

3) White Springs and SR6

At both White Springs and SR6, the data provide a continuous period of record. No long-term trends are indicated in either of the time series. The average concentration at both locations is also similar to the locations below Suwannee Springs. The White Springs data indicate slightly elevated concentrations during 1982 with a few peak values.

The medians analysis at White Springs for the raw unadjusted data show the later time period (1979-1990) to have slightly higher concentrations, but the FAC data show the

difference to be less significant (90%). Additionally, the difference (0.015 mg/L) is about equal to the lowest minimum detection level (0.01 mg/L) of any of the data sets. Similarly, both the raw and FAC data at SR6 show that the difference between the periods before and after 1979 is only 90% significant. At both locations, the monotonic trend analysis shows no significant trend for the time period 1979-1990.

Based on the trend analysis results and the relatively small magnitude of the estimated differences between the time periods before and after the baseline year, no adjustments are made for trends at these two locations.

Total nitrogen. Fanning Springs, Suwannee Springs, and SR6 all have fairly continuous data from 1973 up to 1991. Branford has a continuous record from 1973 through 1983, a data gap from 1984 to 1988, and data covering 1989-1991. Fowlers Bluff, Luraville, and Ellaville have discontinuous data records covering only two time periods, 1982-1983 and 1989-1991. Similar to the phosphorus data, the highest measured total nitrogen values occurred during the late seventies and early eighties. From the time series plots no significant long-term trends are apparent. To evaluate the trends for total nitrogen, the time period before the baseline year (1973-1979) is compared with the period of record after the baseline year (1979-1990). The results of the medians

analyses and monotonic trend analyses are given in Tables 3-22 and 3-23.

Medians analyses for Fanning Springs, Branford, White Springs, and SR6 all indicate that the later time period (1979-1990) has higher concentrations than the period of record prior to the baseline year. Suwannee Springs also indicates the later period has higher concentrations, but not significantly. Luraville, Ellaville, and Fowlers Bluff do not have data prior to the baseline year. At these locations the two periods 1982-1983 and 1989-1990 are compared. At Luraville and Ellaville no significant difference is shown, while at Fowlers Bluff the earlier period (1982-1983) is significantly higher than the later time period. All the monotonic trend analyses indicate no significant trend since the baseline year. Only Fowlers Bluff shows the earlier time period to have higher concentrations than the later time period. The reason for this difference at Fowlers Bluff is not explainable at this time and requires further evaluation.

A general interpretation of the time series plots and trend analyses tends to indicate a small step increase in total nitrogen taking place about 1979-1981, and then the concentration remains fairly constant up to the current time period. With regard to the baseline year the record from 1979 up through the current time period reflects ambient conditions and is not adjusted for trends. To provide a sufficient data base to define ambient conditions, the data record before the

Table 3-22. Summary of Median Analyses on Total Nitrogen

Location	(RAW umhos/cm)	Difference in Medians (UNITS)	Absolute Value of Test Statistic	Significance Confidence Level	(FAC umhos/cm)	Difference in Mediens (UNITS)	Absolute Value of Test Statistic	Significance Confidence Level
Fowlers Bluff	1981-83 to 1989-90	-0.895	3.123	95%	no flow data	-	-	-
Fanning Springs	1974-79 to 1979-90	0.32	4.768	95%	no significant correlation	-	-	-
Branford	1973-79 to 1979-84	0.32	3.912	95%	no significant correlation	-	-	-
	1973-79 to 1989-90	0.14	1.61	80%	no significant correlation	-	-	-
	1979-84 to 1989-90	-0.144	1.678	90%	no significant correlation	-	-	-
	1973-79 to 1979-91	0.26	2.518	95%	no significant correlation	-	-	-
Luraville	1981-84 to 1989-91	0.029	0.165	NS	no flow data	-	-	-
Ellaville	1981-83 to 1989-90	0.099	0.495	NS	no significant correlation	-	-	-
Suwannee Springs	1974-79 to 1979-91	0.120	1.567	80%	no significant correlation	-	-	-
White Springs	1974-79 to 1979-91	0.19	3.51	95%	no significant correlation	-	-	-
State Road 6	1975-79 to 1979-91	0.16	3.20	95%	no significant correlation	-	-	-

Table 3-23 Summary of Monotonic Trend Analyses on Total Nitrogen

Location	(raw umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)	(FAC umhos/cm) Period	Two-sided p value	Confidence Level	Slope Estimate (units/yr)
Fowlers Bluff								
Fanning Springs	1974 to 1990	0.0042	>99.9%	0.027	no significant correlation	-	-	-
	1974 to 1979	0.24	76%	0.015	no significant correlation	-	-	-
	1979 to 1990	0.7408	26%	0.005	no significant correlation	-	-	-
Branford	1973 to 1991	1.616	80%	0.020	no significant correlation	-	-	-
	1979 to 1984	0.025	98%	-0.060	no significant correlation	-	-	-
	1979 to 1991	-1.073	<80%	-0.020	no significant correlation	-	-	-
Luraville	1981 to 1991	0.2405	76%	-0.056	no flow data	-	-	-
	1981 to 1984	0.1489	85%	-0.302	no flow data	-	-	-
	1989 to 1991	0.4008	60%	-0.521	no flow data	-	-	-
Ellaville	1981 to 1991	0.2602	74%	-0.055	no significant correlation	-	-	-
	1981 to 1984	0.0433	96%	-0.293	no significant correlation	-	-	-
	1984 to 1991	0.0929	91%	-0.285	no significant correlation	-	-	-
Suwannee Springs	1974 to 1991	-0.23	<.001%	0.000	no significant correlation	-	-	-
	1974 to 1979	0.702	80%	0.062	no significant correlation	-	-	-
	1979 to 1991	0.06	94%	-0.048	no significant correlation	-	-	-
White Springs	1974 to 1991	0.0887	91%	0.015	no significant correlation	-	-	-
	1974 to 1979	0.8811	12%	-0.013	no significant correlation	-	-	-
	1979 to 1991	0.000	<1%	0.000	no significant correlation	-	-	-
State Road 6	1975 to 1991	0.0896	10%	0.015	no significant correlation	-	-	-
	1975 to 1979	0.4627	54%	0.025	no significant correlation	-	-	-
	1979 to 1991	0.4897	51%	-0.008	no significant correlation	-	-	-

baseline is also included with appropriate adjustments. Where no difference in medians between the data before and after 1979 was indicated, the period of record 1973 to 1979 is included without adjustment. Additionally, where the monotonic trend analysis showed no significant long-term trend the entire data record is used. When a significant difference between the 1973-1979 data and the 1979-1990 data exists, the early data record is adjusted by the difference in means to the later period of record. At Fanning Springs and Branford, the early record is adjusted upward by adding the difference in means. Trend adjustment of the Fowlers Bluff data is not justified without a clear understanding of possible causes for the higher concentrations during 1982-1983. For this analysis no trend adjustment is made in the Fowlers Bluff total nitrogen data.

Summary. Only a slight positive trend was identified in the long-term specific conductance records. Considering characteristics of the sampling frequency, the low flow conditions during the latest period of record, and the insignificant magnitude of the estimated trend slopes, adjustment of the specific conductance data for trend is not justified. The complete period of record at each location is used to develop the ambient water quality criteria.

Two significant trend periods were identified within the total phosphorus data for the five downstream locations: Fowlers Bluff, Fanning Springs, Branford, Luraville,and

Ellaville. These two periods are increasing trend from 1971 to mid-1982 and a decreasing trend from mid-1982 to 1991. The best water quality with regard to total phosphorus at these locations is the current time period. It is interesting to point out that the magnitude of change due to the increasing trend is approximately equal to the magnitude due to the decreasing trend. This facilitates the use of the data from the entire period of record. By detrending the later record (1979-1991) to the current time period, 1991, and the earlier record (1971-1979) to the 1971 time period, the two records can be combined to represent the current ambient water quality for total phosphorus. Detrending the data at these locations assumes that the trend was caused by some form of human impact (point or nonpoint source discharges). This possible impact has only been qualitatively assessed at this time.

At Suwannee Springs, the complete unadjusted period of record is used for total phosphorus to reflect the permitted discharges in this reach. However, it should be noted that the locations upstream and downstream give an indication of what the conditions were prior to the permitted discharges. Consideration should be given to removing the peak values measured during the late seventies and early eighties. The data record since 1983 does not reflect these high concentrations. Justification for removal of these high concentration values must take into consideration the specific

requirements of the permitted discharge(s) upstream of this reach.

No significant trends were indicated at White Springs or SR6 and the raw unadjusted total phosphorus data are used for representing ambient water quality.

In general, no trends are identified in the total nitrogen data for the period of record since the baseline year. Thus, the period of record since the baseline year represents the ambient water quality. Where no long-term trend or difference in medians was indicated, the period of record 1973 to 1979, is included without adjustment. When a significant difference between the 1973-1979 data and the 1979-1990 data exists, the early data record is adjusted by the difference in means to the later period of record. Fowlers Bluff is the only location that showed the earlier period (1982-1983) to be higher in concentration than the later period (1989-1990). Trend adjustment of the Fowlers Bluff data is not totally justified without a clear understanding of possible causes for the higher concentrations during 1982-1983. For this analysis no trend adjustment is made to the Fowlers Bluff total nitrogen data.

CHAPTER 4
CRITERIA DEVELOPMENT

Literature Review

Beneficial Use Criteria

Historically water quality criteria have been established based on the water quality required to maintain a defined beneficial use. Early publications on water quality criteria focused on obtaining and publishing experimental data on cause-effect relationships of specific parameters on various test organisms (USEPA, 1976). The concept of beneficial use criteria was initiated by Mckee and Wolf (1963) where they reported water quality characteristics according to their effect on various water uses (domestic supply, industrial, irrigation, aquatic life, shellfish and recreation). This concept was formalized in Water Quality Criteria (Federal Water Pollution Control Assoc., 1968), a report of the National Technical Advisory Committee to the Secretary of the Interior. This report focused on five specific uses: public water supply, recreation and aesthetics, fish and wildlife, agricultural, and industrial. The impetus behind this work was the Federal Water Pollution Control Act of 1965 authorizing States and the Federal Government to establish

water quality criteria to protect public health and enhance the quality of water according to objectives of the Act. The recommended criteria represent not only the levels to prevent toxic type responses, but the quality to be maintained or reestablish for the specific beneficial uses. The report also identified the overwhelming lack of available information on many water quality characteristics. Subsequently, the establishment of water quality criteria is a continuous effort. USEPA has a series of publications commonly known as the "Blue Book" (Water Quality Criteria-1972), "Red Book" (Quality Criteria for Water-1976), and "Gold Book" (Quality Criteria for Water-1986) that have updated older criteria and established new criteria as information becomes available. All these documents point out that a constant value criterion does not represent the natural variability of water quality. Reiterating, the objective has been to maintain a specific beneficial use and a single value criterion identifies the minimum quality necessary to maintain that use.

Generally there are two types of beneficial use criteria: numerical and narrative. Numerical criteria have been established where there is sufficient scientific information to support defining a numerical value. Narrative criteria are used primarily when scientific information is inadequate and to recognize background or natural quality. However, narrative criteria that make reference to background water quality in most instances do not define how to numerically

represent background water quality. For example in Florida, natural background is defined as "the condition of waters in the absence of the activity or discharge under consideration." These criteria are subjective in that background concentrations could refer to the mean, median, or some other level of natural background concentration. Representation of background water quality is directly related to the representation of ambient water quality for antidegradation water quality standards.

Criteria established with reference to the receiving water quality are commonly termed water quality based criteria. The development of water quality criteria for antidegradation is synonymous with water quality based criteria.

Water Quality Based Criteria

Numerical representation of ambient water quality must recognize and incorporate the natural water quality variability. This inherently leads to some form of statistical representation. Rosendahl and Rose (1979) applied control chart theory to represent historical water quality for the Everglades National Park. Criteria were represented as control chart upper limits where sample values exceeding these limits are assumed to be violations. This approach requires an assumption that the data are normally distributed which is most often violated by water quality data.

More recently the use of percentiles to represent ambient water quality has been gaining acceptance. The earliest reference to use of percentiles is in Europe. The National Water Council (London, England) established the concept of river quality objectives (RQOs) based on quality criteria described in terms of the 95th percentile class limits where the 95th percentile represents the value achieved by 95 percent of the samples taken (Crabtree et al., 1986). Use of percentiles have now become standard practice in several European countries (Bernard, 1988).

Summaries of phosphorus and nitrogen water quality criteria within the United States, conducted by EPA, show that Arizona, Nevada, Hawaii, and American Samoa have adopted percentile type criteria for these nutrient parameters (USEPA, 1988a & 1988b). In Arizona for some selected streams total phosphorus and total nitrogen concentrations are established for the annual mean, 90th percentile and single sample maximum. The Nevada Department of Environmental Protection defines their ambient water quality criterion as "requirements to maintain existing higher quality" (RMHQ). They represent the RMHQs with two criteria: 1) the 95th percentile of the annual average concentrations, and 2) the single value maximum (NDEP, 1987). The 95th percentile is defined as the 95th ranked value of the sample population distributed into one hundred evenly divided increments.

Hawaii and American Samoa have defined criteria for total phosphorous and nitrogen in terms of the geometric mean (50^{th} percentile), 90^{th} percentile and 98^{th} percentile for both wet and dry periods (USEPA, 1988a & 1988b). The database available to develop the percentiles was short and the data were assumed to fit a lognormal distribution (Krock and Sullivan, 1986). In addition to the percentiles, confidence intervals for the lognormal fit to the data are used to determine the number of samples necessary to provide a specific confidence level for determining compliance with the criteria.

Breidt et al. (1991) develop antidegradation water quality criteria in terms of confidence intervals around a selected percentile. The confidence intervals are based on the binomial distribution where the percentile represents the probability of the binomial event. The methodology makes no assumption with regard to the distribution of the sample population and is thus termed distribution free. Because the percentile of interest is not specifically estimated, Briedt et al. (1991) propose that any value between the confidence interval can be chosen. Establishing a confidence interval recognizes the variability or accuracy of the percentile estimate. Berthouex and Hau (1991) identify the variability of estimating the 99^{th} percentile and recommend a "fuzzy region" confidence range around the estimated percentile.

This range is essentially provided by development of confidence intervals for the estimated percentile.

Related to the use of percentiles for representation of water quality criteria, Loftis and Ward (1981) used the concept of percentiles to estimate the probability of stream water quality violations. The percentile of the beneficial use criterion is determined from the cumulative distribution of the stream water quality and subsequently represents the expected number of values that exceed the criterion. Similarly, Male and Soucie (1989) evaluate water quality excursions assuming the data fit a lognormal distribution.

Recent work with regard to water quality based criteria for toxics uses three components for defining a specific criterion: 1) magnitude, 2) duration, and 3) frequency (USEPA, 1991). The duration is the time period over which the parameter concentration (magnitude) is averaged and it is often referred to as the averaging period. The magnitude and duration are established based on laboratory toxicity tests. The magnitude is based on the concentration that produces a specific toxicity effect and the duration relates to the exposure time of the toxicity test. The duration for an acute response (hours) is shorter than the duration for a chronic response (days). The frequency is established somewhat arbitrarily, based on a desirable exceedence frequency for the defined event (EPA, 1991).

Magnitude, duration and frequency provide a complete description of the water quality event of interest. These values provide an added dimension to the use of percentiles whereby a return period can be associated with any selected percentile. Percentiles do not necessarily represent return period unless the data used to establish the percentiles are independent and evenly spaced in time. Percentiles based on instantaneous measurements only reflect an instant in time versus the possible duration of an event. The use of magnitude, duration and frequency is incorporated into the concept of criterion event definition. The criterion event definition (CED) will depend on the cause-effect relationship of the water quality parameter being evaluated. The ability to statistically represent the event of interest will depend on characteristics of the ambient water quality data.

Percentile Estimation

With respect to water quality data a percentile represents the percentage of data values that are less than or equal to a specified magnitude of concentration. The percentile is related to frequency when the data being evaluated are independent. The relationship between percentile and frequency is discussed in the next section.

Percentiles can be estimated using parametric or nonparametric methods. Parametric procedures consist of either assuming a known distribution or fitting a known distribution

to the data and estimating the parameters of the distribution using the data. The estimated parameters are then used in the cumulative density function of the known distribution to calculate selected percentiles. This is a common approach used in flood frequency analysis where the data being analyzed are typically a series of annual maximum daily flows. Three of the more common distributions fit to the data are the lognormal, log Pearson Type 3, and Extreme Value Type I (Gumbel). The lognormal distribution is commonly used to represent water quality data (Crabtree et al., 1987; Crabtree and Cluckie, 1986; Harris, 1987; Di Toro, 1984; and Male and Soucie, 1989; Warn and Brew, 1980). One advantage to using a known distribution is when the available data set is small the distribution parameters can still be estimated for an assumed distribution. Crabtree et al. (1986) and Crabtree and Cluckie (1986) evaluated the normal, lognormal and Pearson Type 3 distributions for 334 river and effluent data sets showing that only 50 percent of the data sets could be fit to a parametric distribution and for those that fit the Pearson Type 3 had a greater frequency of fit. Crabtree et al. (1986) recommended a nonparametric method for the data that do not fit a known distribution.

Parametric and nonparametric methods for estimating percentiles have been compared based on data generated from known distributions (Berthouex and Hau, 1991; Ellis and Lacey, 1980; Loftis and Ward, 1981). Berthouex and Hau (1991)

estimated percentiles for lognormal generated data using a lognormal distribution fit and a nonparametric method and indicate the lognormal fit provides a better estimate. This is to be expected since it is the true underlying distribution. Ellis and Lacey (1980) compared estimates of the 95th percentile using a normal distribution and a nonparametric method on data generated from a normal distribution and data generated from the combination of two different normal distributions. Their results show that for the normal generated data both methods perform well with the nonparametric estimate having slightly higher variability. Again this is expected because the underlying distribution was normal. For the nonnormal (combined distribution) data the nonparametric method provided a significantly better estimate. Loftis and Ward (1981) compared the estimates of the 95th percentile using a normal distribution and a nonparametric method for data that were approximately normal and concluded that the two models gave similar results. These comparisons do not recognize that the nonparametric method for estimating the percentile is a function of the underlying distribution. Appropriate nonparametric methods are recommended for various distributions and are discussed later (Cunnane, 1978).

The primary drawback to using a nonparametric approach is the requirement for larger data sets. To establish a 95th percentile requires a minimum of 20 observations. The advantage of a nonparametric approach is that it can be

applied to any data set independent of any underlying distribution. The characteristics of water quality data and the variability of appropriate known distributions makes the use of nonparametric methods highly applicable to water quality data.

Nonparametric Methods

The nonparametric approach to estimating percentiles is based on rank statistics. The theory for percentile estimation is thus established through order statistics where we want to estimate the expected value that defines the p^{th} percentile. The theory of order statistics is based on the original random sample from a continuous population with probability density function f_X composed of independent, identically distributed random variables with joint density function

$$f_{X_1, X_2, \ldots, X_n}(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} f_X(x_i) . \qquad 4\text{-}1$$

The joint probability distribution of the n order statistics for the referenced random sample is derived using the method of Jacobians for transformations (Gibbons, 1985) resulting in

$$f_{X_{(1)}, X_{(2)}, \ldots, X_{(n)}}(y_1, y_2, \ldots, y_n) = n! \prod_{i=1}^{n} f_X(y_i) \qquad 4\text{-}2$$

$$for\ y_1 < y_2 < \ldots < y_n.$$

Subsequently the marginal distribution of the r^{th} order statistic is found in the usual manner by integrating out the remaining n - 1 variables in the joint distribution (4-2). The result of the integration as presented by Gibbons (1985) is

$$f_{X_{(r)}}(y_r) = \frac{n!}{(r-1)!\,(n-r)!}[F_X(y_r)]^{r-1}[1-F_X(y_r)]^{n-r}f_X(y_r). \quad 4\text{-}3$$

From the definition of expected value for the r^{th} order statistic

$$E(X_r) = \int y_r\, f_{X_{(r)}}(y_r)\, dy_r, \quad 4\text{-}4$$

it is clear that the estimate of the percentile based on order statistics depends on the parent distribution of the random variable. Determining the expected value of the r^{th} order statistic is limited by the ability to integrate the cumulative density function of the parent population F_X. For the uniform population over the interval (0,1) Gibbons shows the mean of the r^{th} order statistic to be

$$E(X_r) = \frac{r}{n+1} \quad 4\text{-}5$$

for any $1 \leq r \leq n$. For the distributions most often used to represent water quality (normal, lognormal and Pearson Type 3) the integration is impractical or must be solved numerically.

Several ranking formulas are referenced in the literature to define plotting positions in frequency analysis of flow data (Viessman et al. 1989; Bedient and Huber, 1988). These formulas represent the nonparametric approach to percentile estimation and are often referred to as empirical frequency formulas. The most common plotting position formula is the Weibull formula

$$F(x) = \frac{m}{n + 1} \qquad 4\text{-}6$$

where m is ranked from lowest to highest and F(x) represents the percentage of observations less than the m^{th} ranked value. Cunnane (1978), showed that the Weibull formula only represents the largest value frequency for the uniform distribution which is also indicated above for the expected value of the r^{th} order statistic from a uniform population (4-5). Typically, most hydrologic data are represented by lognormal or extreme value distributions.

Cunnane (1978) evaluated the general form first presented by Gringorton (1963)

$$F(x) = \frac{i - \alpha}{N + 1 - 2\alpha} \qquad 4\text{-}7$$

determining the coefficient based on least squares fit to known distributions. Recommended values for α are 3/8 for the normal distribution, and 0.44 for the extreme-value type-1

(Gumbel distribution) and exponential distributions. For the Wiebull formula $\alpha = 0$. For a single simple distribution free formula Cunnane (1978) recommends $\alpha = 2/5$. Thus, for nonparametic estimation of percentiles the Gringorton formula with $\alpha = 2/5$ is used.

For percentile estimation the data are sorted from lowest to highest and ranked by assigning the lowest concentration a rank equal to one and the highest concentration a rank equal to the number of data points n.

It should be clearly understood that the percentiles estimated using the complete data set of instantaneous observations only represent the percentage of observations that are less than or equal to a selected concentration level. A point on the cumulative percentile distribution simply identifies on the average, the percentage of parameter observations that have been less than or equal to the selected concentration value. It does not provide information on the recurrence interval (return period) or probability of the event because the values in the complete series are not necessarily independent (Searcy, 1959).

Confidence Intervals

Confidence limits reflect the accuracy by which the estimated percentile represents the "true" percentile by defining upper and lower limits on the estimated percentile. This information provides decision makers with a range within

which estimated values are acceptable. Confidence limits for the estimated percentiles can be approximated using the binomial distribution, which is a distribution-free technique (Breidt et al., 1991; Gibbons, 1985). This technique has been applied by Loftis and Ward (1981) and Breidt et al. (1991). The estimated percentile essentially becomes the probability, p, of a "success." A success is then defined relative to the selected percentile X_m. For example, there is a 50 percent chance (p) that an individual measurement will be less than or equal to the concentration associated with the 50th percentile X_{50}. The confidence interval is established by selecting a desired confidence level, say .95 = 1 - α (95 percent confidence interval), and setting the lower limit equal to $X_{(L)}$ and the upper limit $X_{(U)}$. The confidence interval is now defined as

$$P(X_{(L)} < X_{(m)} < X_{(U)}) = 1 - \alpha \ . \qquad 4\text{-}8$$

The logical choices for the confidence interval end points are two order statistics from the random sample that provide a solution to (4-8). The confidence interval in terms of the binomial is (Gibbons, 1985)

$$P(X_{(L)} < X_{(m)} < X_{(U)}) = \sum_{i=L}^{n} \binom{n}{i} p^{i}(1-p)^{n-i} - \sum_{i=U}^{n} \binom{n}{i} p^{i}(1-p)^{n-1} \qquad 4\text{-}9a$$

$$= \sum_{i=L}^{U-1} \binom{n}{i} p^i (1-p)^{n-i}. \qquad 4\text{-}9b$$

Breidt et al. (1991) solved this formulation of the confidence interval by first finding the smallest value of U that satisfied the inequality (4-9a) and with fixed U solved for the largest value of L which gives at least the desired confidence interval. Because the only choices available for U and L are integers the confidence interval will not be exact but represents the width closest to the desired interval. There are other possible choices for L and U such that the inequality (4-9a) will be met. The approach used by Briedt et al. (1991) is conservative in that it minimizes the upper confidence level. This somewhat goes against the characteristics of the percentile estimates in that the higher percentiles have much poorer estimates and it might be more logical to make the confidence interval even or weighted to the upper side of the estimated percentile value.

An alternative approach presented by Loftis and Ward (1981) defines the lower and upper confidence intervals as follows:

$$X_{(L)} = L/n$$

where L is the largest integer for which

$$\sum_{i=0}^{L} \binom{n}{i} p^i (1-p)^{n-i} \leq \frac{\alpha}{2} \qquad 4\text{-}10$$

and $X_{(U)} = U/n$

where U is the smallest integer for which

$$\sum_{i=U}^{n} \binom{n}{i} p^{i}(1-p)^{n-i} \leq \frac{\alpha}{2}. \qquad 4\text{-}11$$

This approach results in a confidence interval that is more evenly weighted above and below the estimated percentile. Tables for evaluating the binomial distribution are given in several standard statistical texts (Miller and Freund, 1977). The confidence limits for α = .01 and .05 are tabulated by Pearson and Hartley (1966).

Criterion Event Definition

The criterion event is defined by establishing the frequency and duration. With the frequency and duration selected the ambient water quality data are analyzed to estimate the magnitude of the event using the nonparametric percentile procedures discussed previously.

Event Frequency

The objective for defining frequency is to associate a return period with a water quality criterion. A true frequency will provide for assessment of the risk of exceeding the defined event naturally. Frequency analysis for a selected event identifies the average recurrence interval or

return period (T) between events equaling or exceeding a specified magnitude. The exceedence probability (P) of the defined event is the inverse of the return period (1/T). For frequency analysis the event definition used must generate a series of data values that are independent. Common events defined in hydrology are the annual maximum and annual exceedence series. The annual maximum series consists of the largest measured concentration for each year of available record and each annual maximum is assumed to be independent. The annual exceedence series consists of n maximum measurements over the n year period of record not necessarily the maximum of each year. For example, when one year has three measurements that all exceed the maximum measurement from another year, all three higher values from the one year are selected for frequency analysis before the one maximum of the other year. The difficulty in establishing the annual exceedence series is that the events must be independent. The selection of independent measurements for the exceedence series is somewhat subjective and most often requires manually reviewing each data set. The return period can also be defined in terms of weeks, months or quarters as long as the data are independent.

In the application of water quality based criteria for toxics control the frequency is established using the concentration-duration curve of daily values generated by Monte Carlo simulation (Limno-Tech, 1985; USEPA, 1991a). The

concentration-duration curve represents all the data in a historical time series and truly only defines the percent of time a specific magnitude is equaled or exceeded. Theoretically, use of the concentration-duration curve (complete series) to establish return period is incorrect because the values in the complete series are not necessarily independent (Searcy, 1959). Alternatively the complete series can be used to define specific events that are independent such as the annual maximum.

The historical water quality data available for analysis will typically represent infrequent sampling which varies over time. A typical water quality data set might be referred to as a partial complete series. This type of data set is not amenable to frequency analysis. The criterion event definition must be made such that the data series generated is independent.

For data series that are independent the exceedence probability and the percentile probability are directly related. The exceedence probability P (prob($X \geq x$)) is equal to one minus the percentile probability F (prob($X \leq x$)). Both are related to the return period accordingly

$$T = \frac{1}{P} \qquad 4\text{-}12$$

$$P = 1 - F \qquad 4\text{-}13$$

$$T = \frac{1}{(1 - F)} \quad . \qquad 4\text{-}14$$

For a given sampling frequency and assuming the measurements are independent, an estimated percentile defines the return period. A common sampling frequency used for water quality monitoring is monthly. If one assumes the monthly samples are independent then the return period associated with the 95th percentile is

$$T = \frac{1}{(1 - .95)}$$
$$= 20 \; months$$
$$\approx 1.7 \; years,$$

whereas for an annual event the 95th percentile will represent a twenty year return period. Thus, as the event for the criterion is established in terms of percentile it is important to consider the sampling frequency within the event definition.

Event Duration

The objective of defining a duration is to recognize that the critical water quality events to be managed are not all necessarily instantaneous events of extreme magnitude. The selection of a percentile based on a complete or partially complete series only represents a single instantaneous event. The criterion event definition should consider the cause-

effect character of the parameter being evaluated. Toxic parameters typically have short response times, on the order of hours to days. Whereas, the response to increased concentrations of nutrients is likely to be on the order of months to years, depending on the level of increase in concentration. Additionally, water quality changes due to nonpoint source pollution are more characteristic of gradual changes in average conditions over relatively long time periods. Subsequently, a duration can be defined to better reflect the response time of a specific parameter and provide for long-term water quality management.

The duration represents a time period over which several samples are collected and averaged (averaging period). For example, a monthly average would be the average of all the daily samples collected during that month. In most cases the sampling frequency at which the available data were collected will be the limiting factor in establishing the averaging period. To estimate a monthly average, several daily measurements are required throughout the month. When sampling is done on a monthly basis, a monthly average cannot be truly represented. Recognizing that water quality data are most often collected on a monthly basis, quarterly or yearly averaging periods are the shortest that can be justified. However, this assumes that four samples per quarter or twelve samples per year will reflect average conditions.

Although the emphasis here has been on selecting a duration over which average conditions define the event, extreme concentrations of short duration must still be considered. Thus, for a selected duration two events are defined: 1) the average concentration over the selected duration, and 2) the maximum instantaneous concentration that occurs during the duration.

For monthly water quality data several events can be defined. Recognizing the seasonal variability of water quality it would be logical to define events that relate to the defined seasonality. Another logical choice would be definition of annual events. For application to the Suwannee River data, quarterly criterion event definitions would consist of the maximum and average concentrations for each quarter within each year. The quarterly average and maximum values can be arranged into three possible data series: 1) quarterly series consisting of all quarterly maximum or average values, 2) annual seasonal series consisting of the maximums or averages from one season for each year, or 3) annual series consisting of the maximum quarterly values or maximum quarterly averages for each year. It would not be reasonable from a management perspective to establish all three series as criteria. Recognizing the recent interest in seasonal water quality discharge permits annual seasonal series are developed for the Suwannee River data. The annual seasonal series percentiles are developed and compared with

the percentiles based on the complete data set. The final selection of the criterion event definition for establishing water quality criteria is a management decision.

Application to the Suwannee River: Results

The concept of percentile criteria is applied to the Suwannee River water quality data. The trends, flow relationships and seasonality identified in Chapter 3 are recognized here to establish the water quality percentiles representative of ambient conditions with respect to the baseline year (March, 1978 through February, 1979). The analysis does not focus on any specific percentile concentration, but develops a cumulative percentile distribution for different conditions that reflect the available data. Subsequently, any percentile of interest can be identified and applied as a numerical criterion.

The final results consist of ambient water quality percentiles, seasonal-ambient percentiles and confidence intervals on the estimated percentiles for the complete data series. In addition to the complete data series, annual quarterly averages and maximums are developed for each season, and annual maximums and exceedences are evaluated for comparison.

Initially two questions raised during the data analysis are addressed: 1) Can deseasonalization account for concentration-flow relationships? 2) How well does a combined

total phosphorus data set compare to a single total phosphorus data set? The data sets at the Branford location have been used to evaluate these two questions.

Deseasonalization vs. FAC

At Branford, specific conductance and flow are significantly correlated with an R^2 of .67. The raw and FAC specific conductance data are both deseasonalized by subtracting the mean and dividing by the standard deviation (SD). The objective here is to identify whether or not deseasonalized raw data are equivalent to deseasonalized FAC data. The 95^{th}, 50^{th}, and 5^{th} percentiles are given in Table 4-1 for both data sets. Figure 4-1 gives a plot of the continuous percentiles for the deseasonalized data sets. Essentially, there is no significant difference between the two deseasonalized data sets. This was also confirmed by using the Mann-Whitney test which indicated no difference between the two data sets. This comparison indicates that variability due to flow can be accounted for by simply deseasonalizing the data. Although this comparison was only made at Branford, it is assumed to represent all locations. Thus, for water quality monitoring locations where flow data are not available, deseasonalizing will sufficiently account for variability due to flow. Therefore, a uniform approach can be applied at all locations utilizing deseasonalization to represent flow-concentration relationships.

Table 4-1. Comparison of Percentiles for Deseasonalized RAW and FAC Specific Conductance at Branford

Percentile	DESEASONALIZED DATA	
	RAW (umhos/cm)	FAC (umhos/cm)
0.99	1.755	2.147
0.95	1.362	1.593
0.9	1.196	1.386
0.8	0.906	0.931
0.7	0.669	0.596
0.6	0.424	0.240
0.5	0.138	-0.102
0.4	-0.166	-0.386
0.3	-0.570	-0.636
0.2	-1.028	-0.897
0.1	-1.324	-1.290
0.05	-1.715	-1.576

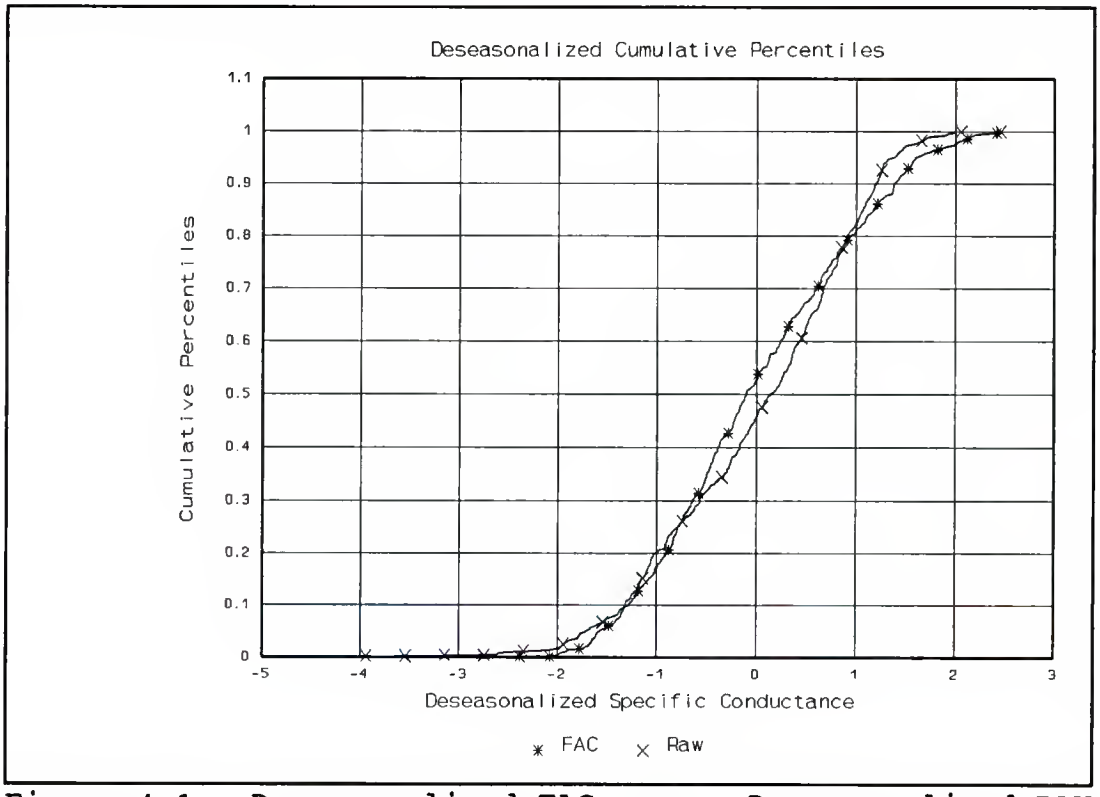

Figure 4-1. Deseasonalized FAC versus Deseasonalized RAW Specific Conductance at Branford

Individual vs. Combined Data

Comparison of the different agency data sets at the five downstream locations (Fowlers Bluff, Fanning Springs, Branford, Luraville and Ellaville) showed that total phosphorus data were the least compatible to combining into one data set. The three phosphorus data sets at the Branford location did not compare for any of the conditions evaluated. The longest consistent record for phosphorus at Branford is the 112WRD 02320500 data set (USGS). Continuous percentile distributions are developed for both the 112WRD data set and the combined data set. By comparing the distributions for the two data sets, the effect of combining the data sets can be somewhat quantified.

Initially, trend is removed from both data sets using the slope estimates given in Chapter 3. A positive trend of 0.0225 mg/l per year is removed from the 1971 to mid-1982 period of record and a trend of -0.022 mg/l per year is removed from the mid-1982 to 1991 period of record. Upon removing the trend, some of the values are below the minimum detection level. All values below 1/2 the minimum detection level (0.05) were adjusted up to 1/2 the minimum detection level.

Table 4-2 gives concentration values for both data sets. The continuous percentile distributions for the combined and individual 112WRD data sets are given in Figure 4-2. From the figure, the difference between the two distributions is only

apparent at very low concentrations. This reflects the difficulty in analytical measurement of low phosphorus concentrations. Whereas, at higher concentrations the analytical variability is reduced. A Mann-Whitney test comparing the two data sets indicated they were not significantly different. Thus, the concerns often expressed regarding differences in lab techniques, sampling etc. do not necessarily represent significant differences in the end result. Where compatibility of different phosphorus data sets is not indicated by the data aggregation analysis, it will not limit the use of the combined data sets. Because there is insignificant difference between the two data sets the combined data sets for total phosphorus are used at all locations.

Ambient Water Quality Percentiles

The ambient water quality data sets for each parameter at each location incorporate the adjustments for trends identified in Chapter 3. The percentiles are developed for the ambient water quality data for each parameter at each location. The percentiles represent the magnitude and variability of the ambient water quality. The percentiles for each water quality parameter are compared from upstream to downstream to identify possible uniformity along the River.

Specific conductance. Unadjusted specific conductance data are used to represent ambient water quality. Table 4-3

Table 4-2. Comparison of Percentiles for 112WRD and Combined Total Phosphorus at Branford

Percentile	Total Phosphorus Concentration	
	112WRD (mg/l)	COMBINED (mg/l)
0.99	0.886	0.747
0.95	0.398	0.410
0.8	0.227	0.228
0.7	0.192	0.179
0.6	0.167	0.161
0.5	0.146	0.126
0.4	0.126	0.112
0.3	0.110	0.089
0.2	0.096	0.061
0.1	0.080	0.050
0.05	0.058	0.050

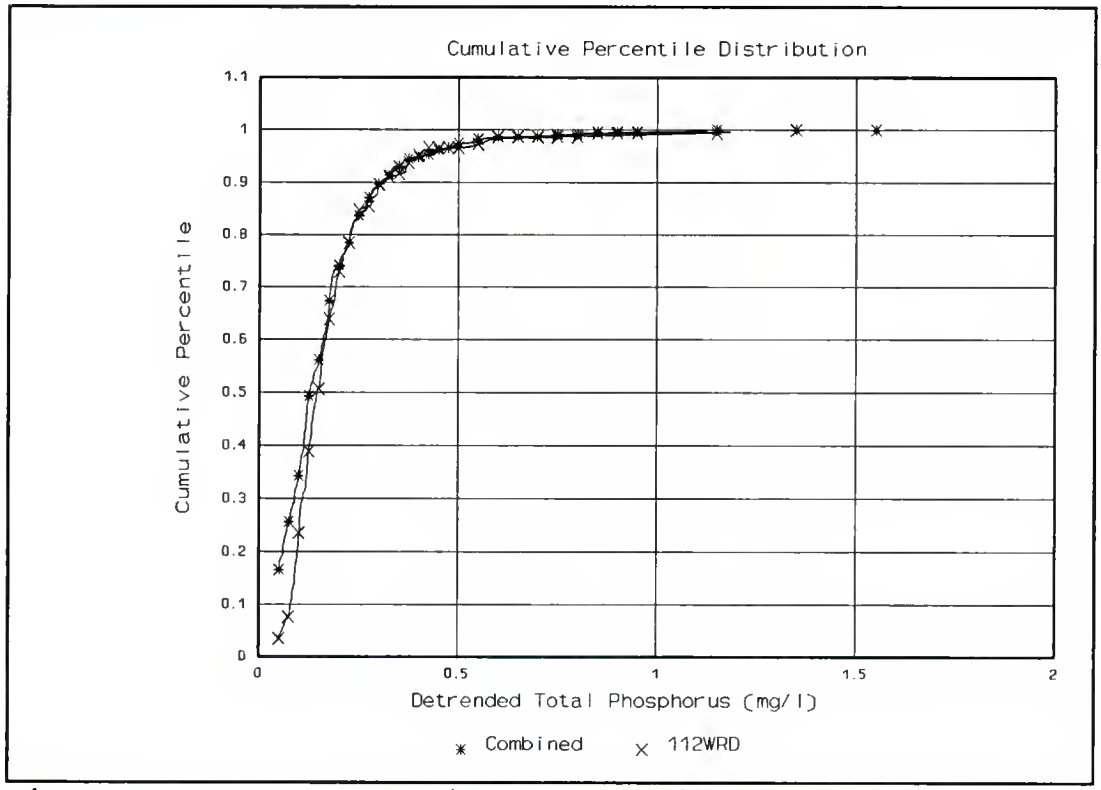

Figure 4-2. Cumulative Percentiles for 112WRD and Combined Total Phosphorus at Branford

summarizes selected percentiles at each location along the river. The concentrations are plotted in Figure 4-3 providing a downstream to upstream profile along the river for each percentile. Table 4-4 gives the specific conductance concentration for several percentiles at each location.

A comparison of different locations, shows that the selected percentile concentrations are fairly uniform for different reaches of the River. For specific conductance the monitoring locations can be grouped into four reaches. Fowlers Bluff, Fanning Springs, and Branford make up the first reach. The 50^{th} percentile concentrations at these three locations are 243.0, 238.0, and 245.0 umhos/cm, respectively and the maximum difference is only 7 umhos/cm which is less than 3% of the median concentration. The percentile concentration differences are higher for the tail percentiles (5^{th} and 95^{th}), which is expected due to the higher error involved with estimating the highest and lowest percentiles. The other locations that can be grouped together are Luraville and Ellaville, and White Springs and State Road 6. Suwannee Springs clearly represents a transition reach and is grouped by itself.

The median specific conductance concentration ranges from a high of 243 umhos/cm at Fowlers Bluff to a low of 55 umhos/cm at State Road 6. The maximum 99^{th} percentile concentration is 421 umhos/cm at Fowlers Bluff, which is well below the Class III maximum concentration of 1275 umhos/cm.

Table 4-3. Proposed Ambient Specific Conductance Percentile Points At Selected Locations Along the Suwannee River

LOCATION	RIVER MILE	PROPOSED AMBIENT SPECIFIC CONDUCTANCE PERCENTILE POINTS (umhos/cm)							
		5th	20th	35th	50th	65th	80th	95th	99th
Fowlers Bluff	14.5	79	159	200	243	285	318	357	365
Fanning Springs	32.6	68	140	199	239	271	312	357	421
Branford	75	59	133	201	245	280	312	337	373
Luraville	97.1	47	100	154	193	238	281	328	348
Ellaville	126.9	46	86	138	183	230	265	321	338
Suwannee Springs	149.6	42	60	73	104	144	207	308	369
White Springs	171.1	37	46	51	57	64	77	108	146
SR6	195.8	41	48	52	55	59	66	83	122

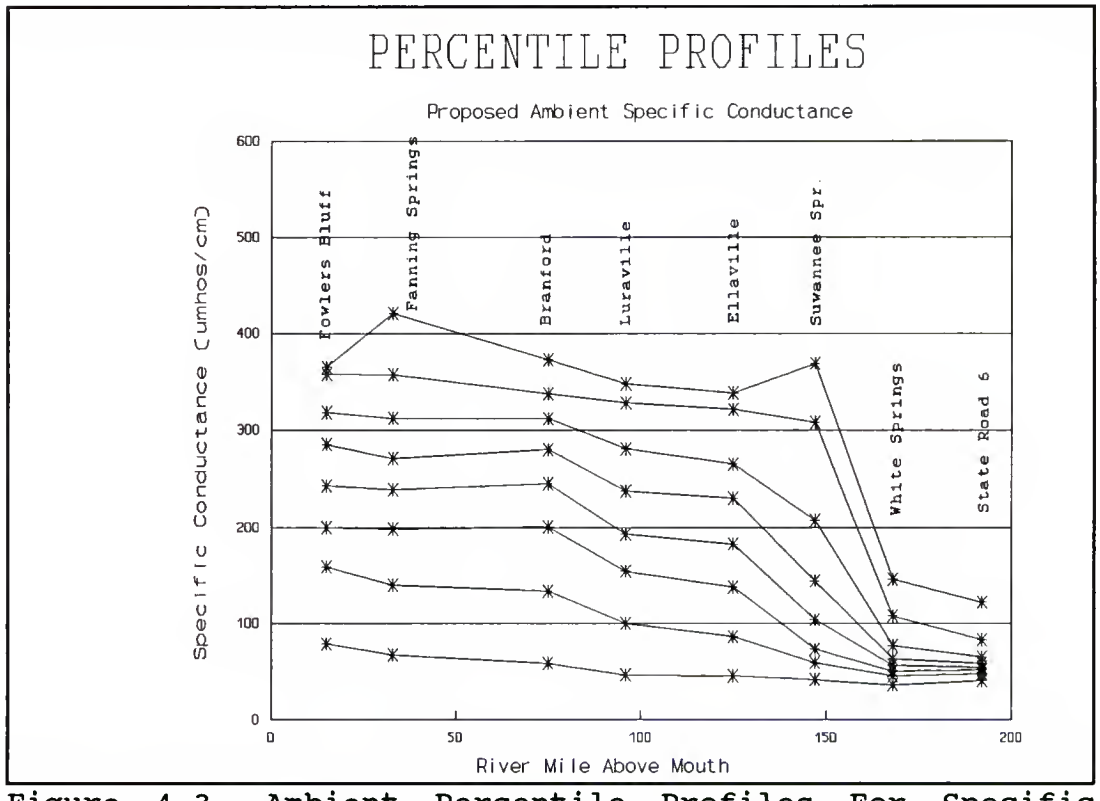

Figure 4-3. Ambient Percentile Profiles For Specific Conductance representing sequentially from top to bottom the 99th, 95th, 80th, 65th, 50th, 35th, 20th and 5th percentiles.

Table 4-4. Percentile Table for Ambient Specific Conductance Water Quality

Percentile	Specific Conductance Concentration (umhos/cm)							
	Fowlers Bluff	Fanning Springs	Branford	Luraville	Ellaville	Suwannee Springs	White Springs	State Road 6
0.050	79	68	59	47	46	42	37	41
0.100	124	90	81	62	64	48	41	43
0.150	135	114	109	80	77	55	43	46
0.200	159	140	133	100	86	60	46	48
0.250	176	160	156	117	98	64	47	50
0.300	187	175	188	130	127	69	49	51
0.350	200	199	201	154	138	73	51	52
0.400	210	214	216	166	150	79	53	53
0.450	227	225	231	178	167	91	55	54
0.500	243	239	245	193	183	104	57	55
0.550	261	247	255	207	196	110	59	56
0.600	267	262	268	221	213	127	61	58
0.650	285	271	280	238	230	144	64	59
0.700	297	290	292	250	244	159	68	60
0.750	313	300	302	266	253	176	72	63
0.800	318	312	312	281	265	207	77	66
0.850	331	320	321	292	272	248	84	69
0.900	344	333	329	306	289	265	93	77
0.950	357	357	337	328	321	308	108	83
1.000	365	500	410	360	339	390	166	179

Total phosphorus. The total phosphorus data at the monitoring locations downstream of Suwannee Springs are adjusted for trends. Since the baseline year, the total phosphorus concentration has shown a decreasing trend. Subsequently, the data have been adjusted to represent the current time period which reflects the better water quality since the baseline year. At Fowlers Bluff, Luraville, and Ellaville, the data are not continuous and a step reduction is used to adjust the data to the current time period. The step reduction is the difference between the means of the two time periods represented in the data (1982-1983 and 1989-1991). The early time period is reduced by subtracting the difference in the means. At Fanning Springs and Branford the data are continuous over the period 1971-1991. The adjustment at these locations consists of removing a positive trend over the period 1971-1982 and a negative trend from 1982-1991. This adjustment was discussed for the Branford data under the previous section on individual versus combined data.

No adjustments to the total phosphorus data were made at Suwannee Springs, White Springs, and State Road 6. No long-term trends were detected at these locations. The higher concentrations at Suwannee Springs are assumed to incorporate the permitted discharges above this monitoring location which is in accordance with regulations for definition of ambient water quality. However, it should be recognized that the highest concentrations represented by the estimated

percentiles occurred during the late seventies and early eighties. Peak concentrations of similar magnitude have not been detected since about 1984. A specific analysis should be considered to evaluate whether or not these high concentrations are still allowable under current discharge permits above this location. If they are not allowable, then the ambient water quality should be adjusted accordingly to reflect removal of these peak concentrations.

Table 4-5 summarizes selected percentiles at each location along the river. The concentrations are plotted in Figure 4-4, providing a downstream to upstream profile along the river for each percentile. Because of the order of magnitude difference in concentration along the river, two plots at different scales are used to show the differences upstream and downstream of Suwannee Springs. Table 4-6 gives the total phosphorus concentration for several percentiles at each location. The percentiles at Suwannee Springs are three to six times the percentile concentrations at the other locations. At Ellaville we see an initial sharp reduction in the concentrations likely due to dilution. Downstream from Ellaville, the concentrations become gradually less, and at Fowlers Bluff, they are similar to State Road 6. To incorporate the historically permitted discharges, each location has to be considered individually for total phosphorus.

Excluding Suwannee Springs, the median (50^{th} percentile) ranges from a low of 0.08 mg/l at State Road 6 to a high of

Table 4-5. Proposed Ambient Total Phosphorus Percentile Points At Selected Locations Along the Suwannee River

LOCATION	RIVER MILE	PROPOSED AMBIENT TOTAL PHOSPHORUS PERCENTILE POINTS(mg/l)							
		5th	20th	35th	50th	65th	80th	95th	99th
Fowlers Bluff	14.5	0.05	0.05	0.07	0.11	0.14	0.20	0.33	0.38
Fanning Springs	32.6	0.05	0.07	0.09	0.12	0.17	0.22	0.37	0.52
Branford	75	0.05	0.06	0.10	0.13	0.17	0.23	0.41	0.75
Luraville	97.1	0.05	0.09	0.15	0.20	0.23	0.34	0.74	0.95
Ellaville	126.9	0.06	0.15	0.20	0.24	0.28	0.34	0.56	1.04
Suwannee Springs	149.6	0.24	0.45	0.68	0.91	1.34	2.11	4.34	6.32
White Springs	171.1	0.08	0.11	0.15	0.18	0.23	0.33	0.52	0.75
SR6	195.8	0.03	0.05	0.06	0.08	0.10	0.14	0.21	0.35

0.24 mg/l at Ellaville. The highest 99th percentile is 1.04 mg/l at Ellaville (again excluding Suwannee Springs). The 50th and 99th percentile concentrations at Suwannee Springs are 0.91 mg/l and 6.32 mg/l respectively.

Total nitrogen. In general there were no significant trends detected in the total nitrogen data since the baseline year. At Luraville, Ellaville, Suwannee Springs, White Springs and State Road 6, the trend analysis indicated the entire period of record can be used to represent ambient water quality. However, at Fowlers Bluff, Fanning Springs, and Branford, the data before the baseline year were shown to be significantly different from the data following the baseline year. To incorporate all the data for development of the percentiles, the data before the baseline year are adjusted upward to correspond to the data since the baseline year. As previously discussed, a step adjustment is made by adding the

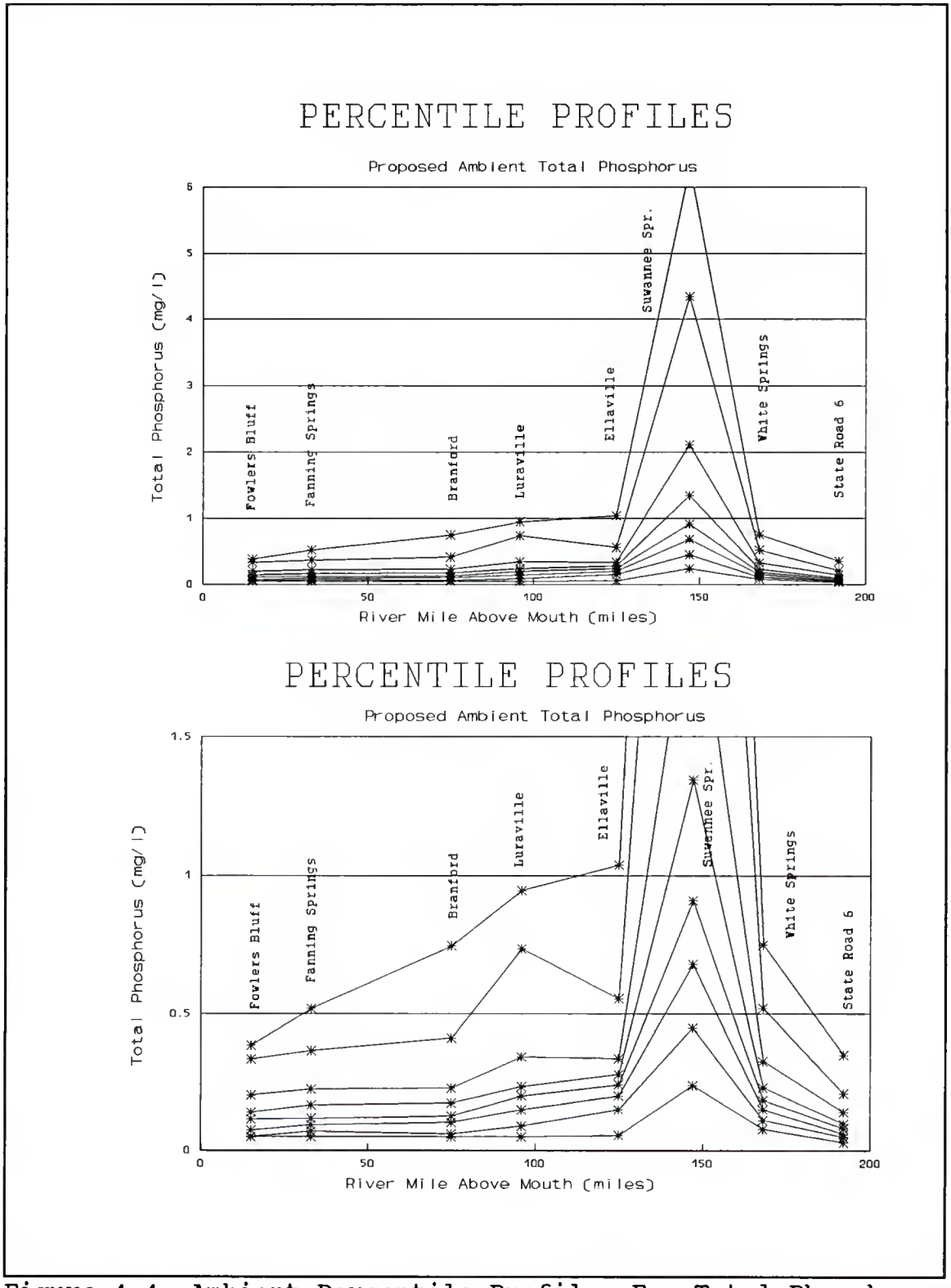

Figure 4-4. Ambient Percentile Profiles For Total Phosphorus representing sequentially from top to bottom the 99th, 95th, 80th, 65th, 50th, 35th, 20th and 5th percentiles.

Table 4-6. Percentile Table for Ambient Total Phosphorus Water Quality

Percentile	Total Phosphorus Concentration (mg/l)							
	Fowlers Bluff	Fanning Springs	Branford	Luraville	Ellaville	Suwannee Springs	White Springs	State Road 6
0.050	-	-	-	-	0.06	0.24	0.08	0.03
0.100	-	-	-	0.05	0.13	0.31	0.09	0.03
0.150	0.05	0.06	-	0.07	0.13	0.37	0.10	0.04
0.200	0.05	0.07	0.06	0.09	0.15	0.45	0.11	0.05
0.250	0.05	0.08	0.07	0.12	0.16	0.53	0.12	0.05
0.300	0.06	0.09	0.09	0.13	0.18	0.61	0.13	0.06
0.350	0.07	0.09	0.10	0.15	0.20	0.68	0.15	0.06
0.400	0.10	0.10	0.11	0.18	0.21	0.75	0.16	0.06
0.450	0.10	0.11	0.12	0.19	0.23	0.81	0.17	0.07
0.500	0.11	0.12	0.13	0.20	0.24	0.91	0.18	0.08
0.550	0.12	0.13	0.15	0.20	0.25	1.01	0.20	0.08
0.600	0.13	0.14	0.16	0.22	0.26	1.20	0.21	0.09
0.650	0.14	0.17	0.17	0.23	0.28	1.34	0.23	0.10
0.700	0.16	0.18	0.18	0.27	0.30	1.70	0.25	0.11
0.750	0.18	0.20	0.20	0.31	0.32	1.90	0.28	0.13
0.800	0.20	0.22	0.23	0.34	0.34	2.11	0.33	0.14
0.850	0.23	0.24	0.27	0.40	0.38	2.55	0.38	0.15
0.900	0.26	0.31	0.31	0.45	0.39	3.40	0.45	0.19
0.950	0.33	0.37	0.41	0.74	0.56	4.34	0.52	0.21
1.000	0.38	0.96	1.13	0.95	1.04	6.90	0.90	0.39

difference in the means between the two time periods (before and after the baseline year). The data before the baseline year are adjusted by adding the difference in means. Although this adjustment results in somewhat poorer quality than that prior to the baseline year, it does represent the current conditions and the adjusted data are used for establishing the proposed ambient water quality criteria for total nitrogen.

Table 4-7 summarizes selected percentiles at each location along the river. The concentrations are plotted in Figure 4-5 providing a downstream to upstream profile along the river for each percentile. Table 4-8 gives the total nitrogen concentration for several percentiles at each location.

Initially at Suwannee Springs we see that total nitrogen concentrations for the 99th and 95th percentiles are about a third higher than the other locations. This impact is much less than that shown for total phosphorus. There is some uniformity between stations for the percentile concentrations up to the 80th percentile. A gradual increase occurs from State Road 6 to Suwannee Springs. Then, the concentration decreases at Ellaville. The concentrations at Ellaville and Luraville are similar. A step increase in concentration occurs between Luraville and Branford and then remains fairly constant to Fanning Springs. At Fowlers Bluff there is a slight increase in concentrations. Variability within the higher percentiles does not indicate any similarities.

Table 4-7. Proposed Ambient Total Nitrogen Percentile Points At Selected Locations Along the Suwannee River

LOCATION	RIVER MILE	PROPOSED AMBIENT TOTAL NITROGEN PERCENTILE POINTS (mg/l)							
		5th	20th	35th	50th	65th	80th	95th	99th
Fowlers Bluff	14.5	0.71	0.94	1.17	1.43	1.77	1.97	2.27	2.46
Fanning Springs	32.6	0.65	0.86	0.95	1.06	1.18	1.33	1.73	2.20
Branford	75	0.61	0.90	1.05	1.15	1.23	1.40	1.84	2.52
Luraville	97.1	0.38	0.61	0.80	0.95	1.15	1.39	2.06	2.40
Ellaville	126.9	0.37	0.59	0.77	0.90	1.20	1.48	1.83	2.75
Suwannee Springs	149.6	0.53	0.94	1.05	1.20	1.40	1.64	2.77	3.73
White Springs	171.1	0.47	0.76	0.85	0.95	1.06	1.34	1.76	2.54
SR6	195.8	0.62	0.77	0.83	0.94	1.00	1.13	1.41	2.14

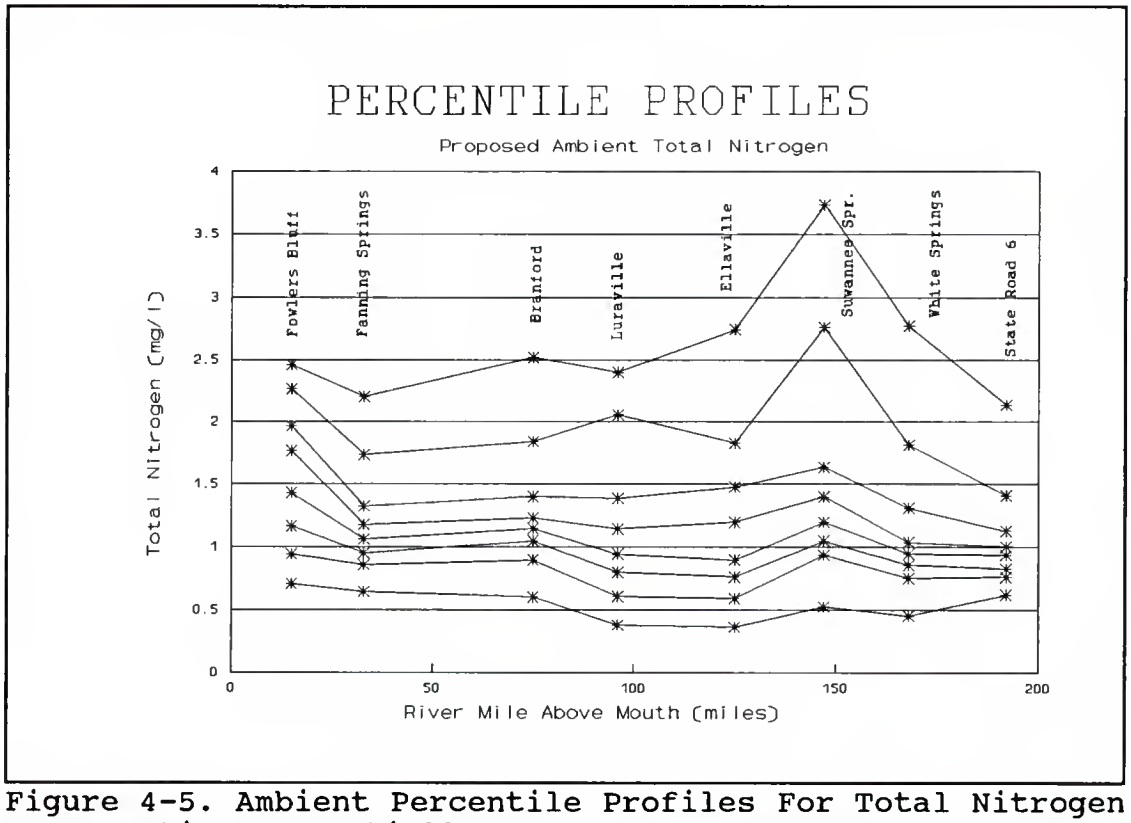

Figure 4-5. Ambient Percentile Profiles For Total Nitrogen representing sequentially from top to bottom the 99th, 95th, 80th, 65th, 50th, 35th, 20th and 5th percentiles.

Table 4-8. Percentile Table for Ambient Total Nitrogen Water Quality

Percentile	Total Nitrogen Concentration (mg/l)							
	Fowlers Bluff	Fanning Springs	Branford	Luraville	Ellaville	Suwannee Springs	White Springs	State Road 6
0.050	0.71	0.65	0.61	0.38	0.37	0.53	0.47	0.62
0.100	0.73	0.77	0.75	0.42	0.44	0.73	0.68	0.68
0.150	0.86	0.81	0.83	0.50	0.54	0.91	0.70	0.71
0.200	0.94	0.86	0.90	0.61	0.59	0.94	0.76	0.77
0.250	0.99	0.90	0.97	0.66	0.65	0.97	0.79	0.79
0.300	1.06	0.93	1.02	0.73	0.69	1.01	0.82	0.82
0.350	1.17	0.95	1.05	0.80	0.77	1.05	0.85	0.83
0.400	1.21	0.99	1.09	0.83	0.80	1.10	0.88	0.87
0.450	1.31	1.03	1.10	0.90	0.87	1.15	0.93	0.91
0.500	1.43	1.06	1.15	0.95	0.90	1.20	0.95	0.94
0.550	1.54	1.11	1.18	1.03	0.98	1.26	1.00	0.96
0.600	1.69	1.16	1.20	1.09	1.03	1.31	1.02	0.98
0.650	1.77	1.18	1.23	1.15	1.20	1.40	1.06	1.00
0.700	1.82	1.22	1.30	1.21	1.30	1.47	1.12	1.02
0.750	1.88	1.26	1.31	1.27	1.38	1.54	1.20	1.09
0.800	1.97	1.33	1.40	1.39	1.48	1.64	1.34	1.13
0.850	2.09	1.39	1.46	1.69	1.63	1.86	1.41	1.22
0.900	2.11	1.48	1.65	1.78	1.75	2.17	1.55	1.26
0.950	2.27	1.73	1.84	2.06	1.83	2.77	1.76	1.41
1.000	2.46	2.23	2.56	2.41	2.82	3.80	2.78	2.43

However, grouping of Fanning Springs with Branford and Luraville with Ellaville could be considered.

The median concentration for total nitrogen (50^{th} percentile) ranges from a low of 0.80 mg/l at Ellaville to a high of 1.2 mg/l at Suwannee Springs. The highest 99^{th} percentile concentration is 3.73 mg/l at Suwannee Springs followed by 2.78 mg/l at White Springs.

Deseasonalized Ambient Water Quality Percentiles

As discussed previously, seasonality will be used to represent variability due to flow and seasonal variability. Subsequent references to variability thus incorporate variability due to flow. By defining seasonal variability changes in water quality above what is expected seasonally can be identified. Using the same methods described above, percentiles are developed for the deseasonalized ambient water quality data. Percentiles for the deseasonalized data are necessary for evaluating possible future changes in water quality that are not due to seasonal variability. Use of the deseasonalized percentiles is presented in the following chapter on applications for water quality management.

Based on the seasonal analysis presented in Chapter 3, a quarterly seasonal cycle starting February 1 is used for each parameter at all locations. The seasonal means and standard deviations are calculated using all the measurements over the period of record for a given season. The calculated means and

standard deviations for each season at each location were given in Tables 3-15, 3-16 and 3-17 for specific conductance, total phosphorus, and total nitrogen respectively.

The ambient water quality data sets for each parameter are deseasonalized by subtracting the seasonal means and dividing by the seasonal standard deviation:

$$C_{ds}=\frac{C_a-S_{c_i}}{STD_{c_i}} \qquad 4\text{-}15$$

where:

C_{ds} = deseasoned concentration for water quality parameter C,

C_a = ambient measured concentration for water quality parameter C,

S_{ci} = mean concentration for water quality parameter C in season i, and

STD_{ci} = standard deviation for water quality parameter C in season i.

This approach to deseasonalization is often used to normalize data. Although normalization is an advantage, the principal reason for using this approach is to account for differences in variance with season. The seasonal statistics are used to deseasonalize the data and subsequently determine the deseasonalized percentiles. The deseasonalized percentile concentrations for each parameter at each location are given in Tables 4-9, 4-10 and 4-11 for specific conductance, total phosphorus, and total nitrogen respectively.

Percentile Confidence Intervals

Upper and lower 95 percent confidence limits for selected percentiles were read directly from the graphical representation of Table 41 in Biometrika Tables for Statisticians (Pearson and Hartley, 1956). These confidence limits are given for the 95th, 90th, 80th, 70th, 60th, and 50th percentiles in Tables 4-12, 4-13 and 4-14 for specific conductance, total phosphorus, and total nitrogen, respectively. The confidence limits for the corresponding lower percentiles can be readily determined from the values given in Tables 4-12, 4-13 and 4-14. For example, the 5th percentile (0.05) lower confidence limit for specific conductance at Fowlers Bluff is 1 minus 0.99 (0.01) and the upper confidence limit is 1 minus 0.87 (0.13). These confidence limits establish bounds on the expected number of measurements that will exceed a given concentration. This concept will be presented by example in the following chapter on application.

General observations show that the confidence intervals are narrower for larger data sets. This points out the importance of long-term continuous water quality data for increased confidence in water quality management decisions. Additionally, the confidence limits are wider for the extreme percentiles compared to the 50th percentile (median) and indicates the larger error involved with estimation of extreme percentiles.

Table 4-9. Percentile Table for Deseasonalized Ambient Specific Conductance Water Quality

Percentile	Deseasonalized Specific Conductance (umhos/cm)							
	Fowlers Bluff	Fanning Springs	Brenford	Lureville	Ellaville	Suwennee Springs	White Springs	State Road 6
0.050	-1.85	-1.75	-1.87	-1.62	-1.54	-1.10	-1.11	-1.13
0.100	-1.40	-1.22	-1.40	-1.17	-1.24	-1.01	-0.94	-0.87
0.150	-1.05	-1.06	-1.16	-1.01	-1.04	-0.90	-0.86	-0.75
0.200	-0.68	-0.85	-0.97	-0.93	-0.91	-0.85	-0.71	-0.65
0.250	-0.57	-0.73	-0.76	-0.82	-0.74	-0.76	-0.67	-0.57
0.300	-0.50	-0.47	-0.52	-0.66	-0.65	-0.62	-0.60	-0.45
0.350	-0.43	-0.34	-0.30	-0.51	-0.57	-0.56	-0.49	-0.37
0.400	-0.20	-0.19	-0.15	-0.38	-0.41	-0.46	-0.44	-0.29
0.450	-0.04	-0.09	0.01	-0.14	-0.20	-0.38	-0.36	-0.22
0.500	0.05	0.04	0.16	0.04	0.03	-0.30	-0.24	-0.15
0.550	0.29	0.16	0.34	0.13	0.25	-0.19	-0.16	-0.13
0.600	0.33	0.33	0.48	0.32	0.38	-0.03	-0.05	-0.05
0.650	0.43	0.50	0.60	0.46	0.47	0.10	0.10	0.07
0.700	0.51	0.60	0.70	0.61	0.58	0.32	0.21	0.16
0.750	0.54	0.72	0.79	0.77	0.76	0.49	0.50	0.23
0.800	0.61	0.81	0.88	0.87	0.85	0.95	0.75	0.37
0.850	1.17	0.93	1.01	1.07	1.11	1.15	0.96	0.70
0.900	1.28	1.16	1.11	1.24	1.30	1.49	1.38	1.00
0.950	1.39	1.35	1.28	1.67	1.49	1.98	1.99	1.61
1.000	2.39	3.66	2.01	2.92	3.12	4.30	3.79	5.43

Table 4-10. Percentile Table for Deseasonalized Ambient Total Phosphorus Water Quality

Percentile	Deseasonalized Total Phosphorus (mg/l)							
	Fowlers Bluff	Fanning Springs	Branford	Luraville	Ellaville	Suwannee Springs	White Springs	State Road 6
0.050	-1.19	-1.00	-0.95	-1.02	-1.12	-0.93	-1.07	-1.30
0.100	-1.06	-0.86	-0.93	-0.99	-1.08	-0.85	-0.89	-1.09
0.150	-0.92	-0.83	-0.84	-0.85	-1.05	-0.76	-0.75	-0.90
0.200	-0.78	-0.74	-0.75	-0.81	-0.89	-0.70	-0.69	-0.76
0.250	-0.71	-0.65	-0.73	-0.71	-0.70	-0.64	-0.63	-0.61
0.300	-0.67	-0.58	-0.63	-0.65	-0.60	-0.59	-0.58	-0.57
0.350	-0.64	-0.54	-0.54	-0.46	-0.53	-0.51	-0.51	-0.51
0.400	-0.51	-0.45	-0.44	-0.38	-0.37	-0.45	-0.45	-0.41
0.450	-0.34	-0.37	-0.32	-0.26	-0.19	-0.39	-0.36	-0.28
0.500	-0.26	-0.23	-0.18	-0.18	-0.17	-0.30	-0.28	-0.24
0.550	-0.23	-0.17	-0.11	0.01	0.01	-0.20	-0.22	-0.14
0.600	0.06	-0.08	-0.03	0.08	0.12	-0.05	-0.07	0.00
0.650	0.17	0.11	0.07	0.17	0.40	0.04	0.00	0.14
0.700	0.57	0.23	0.30	0.22	0.49	0.22	0.15	0.28
0.750	0.76	0.44	0.54	0.42	0.60	0.36	0.40	0.30
0.800	0.82	0.60	0.72	0.84	0.70	0.62	0.58	0.45
0.850	1.05	1.06	0.92	1.19	0.98	1.04	0.98	1.09
0.900	1.57	1.54	1.51	1.46	1.69	1.36	1.44	1.44
0.950	1.89	2.32	2.61	2.11	2.01	2.05	1.93	1.77
1.000	2.01	5.48	13.40	4.58	12.50	4.51	3.99	4.38

Table 4-11. Percentile Table for Deseasonalized Ambient Total Nitrogen Water Quality

Percantile	Desaasonalized Total Nitrogen (mg/l)							
	Fowlers Bluff	Fanning Springs	Branford	Luraville	Ellaville	Suwannee Springs	White Springs	State Road 6
0.050	-1.25	-1.55	-1.49	-1.48	-1.48	-1.20	-1.49	-1.33
0.100	-1.15	-1.09	-1.15	-1.15	-1.24	-0.94	-0.96	-1.10
0.150	-1.10	-0.86	-0.86	-1.09	-1.09	-0.70	-0.87	-0.94
0.200	-0.98	-0.76	-0.67	-0.88	-0.90	-0.66	-0.71	-0.76
0.250	-0.90	-0.64	-0.48	-0.73	-0.79	-0.61	-0.61	-0.63
0.300	-0.85	-0.54	-0.36	-0.63	-0.73	-0.55	-0.54	-0.58
0.350	-0.72	-0.41	-0.31	-0.47	-0.49	-0.46	-0.40	-0.45
0.400	-0.41	-0.27	-0.23	-0.40	-0.44	-0.37	-0.33	-0.36
0.450	-0.33	-0.16	-0.17	-0.30	-0.31	-0.27	-0.20	-0.30
0.500	-0.05	-0.09	-0.06	-0.08	-0.21	-0.19	-0.14	-0.08
0.550	0.31	-0.01	0.05	0.09	-0.16	-0.15	-0.12	0.09
0.600	0.42	0.09	0.10	0.15	0.17	-0.02	-0.05	0.17
0.650	0.67	0.18	0.23	0.23	0.33	0.08	0.09	0.24
0.700	0.77	0.26	0.43	0.37	0.51	0.24	0.15	0.29
0.750	0.83	0.51	0.56	0.53	0.66	0.38	0.32	0.47
0.800	0.96	0.68	0.68	0.84	1.10	0.48	0.66	0.72
0.850	1.16	0.82	0.88	1.05	1.22	0.68	0.83	0.91
0.900	1.32	1.17	1.26	1.46	1.44	1.15	1.18	1.20
0.950	1.48	2.10	1.87	2.10	1.56	2.36	1.87	1.99
1.000	2.22	3.98	3.49	2.35	2.76	3.83	4.02	3.19

Table 4-12. Confidence Intervals About Selected Percentiles For Specific Conductance

Location	Number of Samples	SELECTED PERCENTILES											
		95th		90th		80th		70th		60th		50th	
		Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw
Fowlers Bluff	66	0.99	0.87	0.96	0.8	0.89	0.68	0.808	0.573	0.72	0.47	0.625	0.375
Fanning Springs	315	0.97	0.918	0.933	0.859	0.846	0.75	0.752	0.642	0.655	0.59	0.56	0.442
Branford	532	0.967	0.926	0.925	0.87	0.835	0.758	0.741	0.652	0.645	0.554	0.547	0.452
Luraville	181	0.98	0.905	0.941	0.845	0.856	0.73	0.766	0.621	0.674	0.52	0.578	0.423
Ellaville	240	0.975	0.914	0.935	0.854	0.85	0.748	0.756	0.633	0.66	0.538	0.564	0.439
Suwannee Springs	355	0.97	0.912	0.933	0.859	0.846	0.75	0.75	0.646	0.652	0.541	0.555	0.445
White Springs	243	0.975	0.914	0.935	0.854	0.85	0.748	0.756	0.633	0.66	0.538	0.564	0.439
State Road 6	167	0.98	0.9	0.941	0.84	0.86	0.728	0.771	0.619	0.676	0.515	0.584	0.422

Table 4-13. Confidence Intervals About Selected Percentiles For Total Phosphorus

Location	Number of Samples	SELECTED PERCENTILES											
		95th		90th		80th		70th		60th		50th	
		Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw
Fowlers Bluff	41	0.994	0.832	0.97	0.765	0.908	0.645	0.83	0.536	0.75	0.436	0.661	0.34
Fanning Springs	245	0.975	0.914	0.935	0.854	0.85	0.748	0.756	0.633	0.66	0.538	0.563	0.44
Branford	240	0.975	0.914	0.935	0.854	0.85	0.748	0.756	0.633	0.66	0.538	0.564	0.439
Luraville	54	0.992	0.854	0.965	0.78	0.9	0.668	0.816	0.56	0.739	0.452	0.643	0.359
Ellaville	89	0.986	0.884	0.955	0.82	0.878	0.701	0.759	0.594	0.701	0.488	0.61	0.391
Suwannee Springs	253	0.974	0.914	0.936	0.858	0.849	0.743	0.757	0.637	0.658	0.534	0.561	0.441
White Springs	179	0.98	0.905	0.941	0.84	0.86	0.73	0.766	0.621	0.674	0.52	0.578	0.423
State Road 6	97	0.985	0.885	0.952	0.82	0.875	0.708	0.79	0.598	0.698	0.493	0.605	0.397

Table 4-14. Confidence Intervals About Selected Percentiles For Total Nitrogen Data Sets

Location	Number of Samples	SELECTED PERCENTILES											
		95th		90th		80th		70th		60th		50th	
		Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw	Pup	Plw
Fowlers Bluff	36	0.994	0.832	0.97	0.765	0.908	0.645	0.842	0.523	0.764	0.424	0.675	0.329
Fanning Springs	151	0.98	0.91	0.943	0.837	0.863	0.726	0.774	0.616	0.681	0.511	0.586	0.416
Branford	162	0.98	0.9	0.941	0.84	0.86	0.73	0.768	0.621	0.679	0.515	0.584	0.417
Luraville	69	0.99	0.87	0.96	0.8	0.89	0.68	0.807	0.575	0.72	0.47	0.625	0.375
Ellsville	134	0.988	0.906	0.946	0.831	0.867	0.716	0.776	0.611	0.688	0.506	0.593	0.412
Suwannee Springs	212	0.984	0.925	0.936	0.852	0.85	0.74	0.759	0.631	0.665	0.53	0.57	0.431
White Springs	148	0.98	0.91	0.943	0.837	0.863	0.726	0.774	0.616	0.681	0.511	0.586	0.416
State Road 6	94	0.984	0.885	0.952	0.82	0.875	0.708	0.791	0.599	0.699	0.492	0.607	0.397

Seasonal and Annual Series

The objective for development of the seasonal and annual series is to incorporate the concept of duration by developing a series of seasonal averages and to more clearly define the extreme events. The percentiles for these series are then compared with the ambient and seasonal ambient percentiles.

Two annual series were developed for each season: 1) seasonal averages, and 2) seasonal maximums. The yearly averages and maximums for each season constitute annual-seasonal data series. The data series for each season were ordered and ranked and the percentiles estimated using equation (4-7).

Annual maximum and exceedence series were also generated and percentiles estimated. A uniform approach to establishing the exceedence series was used to provide independent values. The maximum value for each season within each year is determined. From the maximum yearly seasonal values, n maximum values are selected for the annual exceedence series where n is the number of years in the data set. The annual maximum and exceedence series are both sorted and ranked, and the percentiles estimated using equation (4-7).

For comparison of the various percentile concentrations the results for State Road 6, Suwannee Springs and Branford are used. The parameter concentrations for selected percentiles for the seasonal and annual data series are given

in Tables 4-15, 4-16 and 4-17 respectively. The 50^{th}, 65^{th} and 80^{th} percentiles were interpolated linearly between data points as necessary. The higher percentile was chosen for each group to minimize the need for interpolation at the higher end of the distribution.

The ambient and seasonal ambient concentrations for the selected percentiles are given in Tables 4-18, 4-19 and 4-20 for State Road 6, Suwannee Springs and Branford respectively. The ambient percentile concentrations are taken directly from Tables 4-4, 4-6 and 4-8 respectively for specific conductance, total phosphorus, and total nitrogen. The seasonal ambient percentile concentrations are determined by back calculating the concentration using equation (4-15) where the deseasonalized ambient percentiles from Tables 4-9, 4-10 and 4-11 are multiplied by the seasonal standard deviation and then added to the seasonal mean. The deseasonalized percentiles, seasonal standard deviations and means are given in Tables 4-18, 4-19 and 4-20.

Comparison of the different percentile concentrations is qualitative in that each data series represents a different event (random sample). One might expect the annual-seasonal average series to exhibit lower concentrations than the seasonal ambient concentrations for a specific percentile simply due to averaging of seasonal values. Comparison of the annual-seasonal series averages (Tables 4-15, 4-16 and 4-17) with the seasonal ambient concentrations (Tables 4-18, 4-19

Table 4-15. Annual-Seasonal and Annual Series Percentile Concentrations at State Road 6

Specific Conductance (umhos/cm)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	56	53	52	56	60	56	55	58	63	75
65	65	57	57	59	65	57	62	65	73	81
80	68	60	61	61	76	60	71	70	81	90
96	84	78	90	88	179	120	122	94	145	145

Total Phosphorus (mg/l)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	0.05	0.11	0.11	0.07	0.06	0.11	0.12	0.07	0.14	0.19
65	0.06	0.13	0.13	0.08	0.09	0.13	0.15	0.08	0.2	0.2
80	0.08	0.17	0.17	0.1	0.1	0.19	0.22	0.12	0.24	0.24
96	0.28	0.2	0.2	0.14	0.39	0.2	0.28	0.15	0.39	0.39

Total Nitrogen (mg/l)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	0.92	1.01	0.91	0.82	1	1.05	0.99	0.82	1.15	1.3
65	0.98	1.22	0.95	0.89	1.07	1.23	1.03	0.89	1.25	1.35
80	1.08	1.41	1.2	1.07	1.26	1.41	1.24	1.08	1.43	1.44
96	1.26	1.63	1.3	1.23	1.43	2.43	1.45	1.23	2.43	2.43

Table 4-16. Annual-Seasonal and Annual Series Percentile Concentrations at Suwannee Springs

Specific Conductance (umhos/cm)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	76	119	122	143	80	128	150	151	248	262
65	89	173	153	176	104	179	190	187	269	284
80	151	228	206	220	151	248	269	254	306	313
93	205	250	280	300	290	265	335	350	370	370
Total Phosphorus (mg/l)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	0.66	1.2	1.09	1.3	0.73	1.3	1.55	1.54	2.3	3.4
65	0.84	1.5	1.56	1.83	0.94	1.69	2.35	1.87	3.4	4
80	1.12	1.9	2.84	2.48	1.7	2.14	3.56	3.18	4.6	4.6
92	2.5	2.1	3.8	4.45	3.8	2.8	4.2	6.1	6.23	6.23
Total Nitrogen (mg/l)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	1.16	1.18	1.15	1.42	1.29	1.18	1.53	1.45	1.68	2.05
65	1.24	1.28	1.44	1.51	1.51	1.35	1.56	1.51	1.87	2.65
80	1.74	1.48	1.59	1.92	2.25	1.6	1.97	1.92	2.89	3.17
96	2.1	2.07	2.68	2.32	3.7	3.17	3.37	3.8	3.8	3.8

Table 4-17. Annual-Seasonal and Annual Series Percentile Concentrations at Branford

Specific Conductance (umhos/cm)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	139	254	252	274	194	289	301	314	323	336
65	168	284	269	279	230	301	310	328	331	342
80	216	316	285	320	270	326	326	342	349	354
95	266	338	329	340	329	342	342	382	395	395

Total Phosphorus (mg/l)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	0.11	0.12	0.14	0.16	0.17	0.18	0.19	0.23	0.33	0.38
65	0.15	0.14	0.17	0.21	0.19	0.21	0.28	0.32	0.35	0.46
80	0.16	0.16	0.25	0.32	0.26	0.16	0.4	0.41	0.5	0.55
92	0.25	0.22	0.31	0.38	0.32	0.58	0.48	0.83	0.83	0.83

Total Nitrogen (mg/l)										
Percentiles	Annual-Seasonal Series								Annual Series	
	Averages				Maximums				Maximums	Exceedences
	1	2	3	4	1	2	3	4		
50	1.1	1.11	1.17	1.08	1.29	1.2	1.32	1.2	1.48	1.74
65	1.15	1.14	1.29	1.22	1.34	1.31	1.47	1.44	1.63	1.95
80	1.2	1.3	1.35	1.3	1.47	1.45	1.95	1.68	1.9	2.3
95	1.28	1.51	2.52	1.5	1.63	2.11	2.52	2.56	2.56	2.56

Table 4-18. Ambient and Seasonal Ambient Concentrations At State Road 6

Specific Conductance (umhos/cm)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (61/21.7)	2 (55/15.6)	3 (57/13.7)	4 (60/13.7)	
50	-0.15	58	53	55	58	55
65	0.07	63	56	58	61	59
80	0.37	69	61	62	65	66
96	1.91	102	85	83	86	90
Total Phosphorus (mg/l)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (0.07/0.07)	2 (0.11/0.06)	3 (0.12/0.07)	4 (0.08/0.04)	
50	-0.24	0.05	0.10	0.10	0.07	0.08
65	0.14	0.08	0.12	0.13	0.09	0.10
80	0.45	0.10	0.14	0.15	0.10	0.14
96	1.87	0.20	0.22	0.25	0.15	0.22
Total Nitrogen (mg/l)						
Percentile	Daseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (0.94/0.24)	2 (1.15/0.4)	3 (0.92/0.22)	4 (0.87/0.17)	
50	-0.08	0.92	1.12	0.90	0.86	0.94
65	0.24	1.00	1.25	0.97	0.91	1.00
80	0.72	1.11	1.44	1.08	0.99	1.13
96	2.07	1.44	1.98	1.38	1.22	1.43

Table 4-19. Ambient and Seasonal Ambient Concentrations At Suwannee Springs

Specific Conductance (umhos/cm)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (94/64.1)	2 (137/75.6)	3 (142/92.1)	4 (160/96.9)	
50	-0.3	75	114	114	131	104
65	0.1	100	145	151	170	144
80	0.95	155	209	229	252	207
93	1.6	197	258	289	315	285
Total Phosphorus (mg/l)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (0.84/0.92)	2 (1.28/0.98)	3 (1.58/1.39)	4 (2.14/1.71)	
50	-0.3	0.56	0.99	1.16	1.63	0.91
65	0.04	0.88	1.32	1.64	2.21	1.34
80	0.62	1.41	1.89	2.44	3.20	2.11
92	1.67	2.38	2.92	3.90	5.00	3.80
Total Nitrogen (mg/l)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (1.38/0.61)	2 (1.29/0.62)	3 (1.27/0.64)	4 (1.48/0.74)	
50	-0.19	1.26	1.17	1.15	1.34	1.20
65	0.08	1.43	1.34	1.32	1.54	1.40
80	0.48	1.67	1.59	1.58	1.84	1.64
92	1.53	2.31	2.24	2.25	2.61	2.97

Table 4-20. Ambient and Seasonal Ambient Concentrations At Branford

Specific Conductance (umhos/cm)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (159/86.9)	2 (236/80)	3 (251/69.6)	4 (258/89.4)	
50	0.16	173	249	262	272	245
65	0.6	211	284	293	312	280
80	0.88	235	306	312	337	312
95	1.28	270	338	340	372	337
Total Phosphorus (mg/l)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (0.12/0.08)	2 (0.14/0.12)	3 (0.18/0.11)	4 (0.22/0.19)	
50	-0.18	0.11	0.12	0.16	0.19	0.13
65	0.07	0.13	0.15	0.19	0.23	0.17
80	0.72	0.18	0.23	0.26	0.36	0.23
92	1.75	0.26	0.35	0.37	0.55	0.33
Total Nitrogen (mg/l)						
Percentile	Deseasonalized Concentration	Seasonal Ambient Concentrations				Ambient Concentration
		Quarter (mean/std)				
		1 (1.07/0.27)	2 (1.15/0.35)	3 (1.26/0.45)	4 (1.18/0.4)	
50	-0.06	1.05	1.13	1.23	1.16	1.15
65	0.23	1.13	1.23	1.36	1.27	1.23
80	0.68	1.25	1.39	1.57	1.45	1.40
95	1.87	1.57	1.80	2.10	1.93	1.84

and 4-20) generally does not indicate any strong differences between the two data series. The comparison does identify characteristics of the water quality data that limit the duration or averaging period. A primary concern is the effect of sampling frequency on the calculated averages. When only one sample is collected for a particular season it represents both the average and maximum, and when it is a high measurement it can bias the distribution of the averages. This is indicated in the Suwannee River results where the 65th and 80th percentile averages in the second (2) quarter for specific conductance are higher than the seasonal-ambient concentrations. A review of the data shows that nineteen of the twenty-six seasonal measurements are single values. Additionally, when only a few samples are collected during the season a single high measurement can affect the estimated average. The 95th percentile seasonal average concentration for total phosphorus at State Road 6 is higher because the maximum value of record occurred in that quarter.

The hypothesis that the annual-seasonal average series are truly lower is indicated by the specific conductance data at Branford. The specific conductance data at Branford represents the highest sampling frequency for the longest duration of any of the data sets evaluated. The early period of record has a sampling frequency of two to three samples per month. The first and third quarter seasonal averages are clearly lower than the seasonal-ambient concentrations. Thus,

with increased sampling one would expect the seasonal average concentrations to be less than the seasonal-ambient concentrations for the same percentiles. The inconsistent and relatively low sampling frequency causes higher variability in the seasonal average series making water quality management decisions less reliable.

Comparison of both the seasonal-ambient and seasonal average series with the seasonal and annual maximums shows that the high concentrations (extreme events) are not apparent in the percentiles that are commonly selected for water quality criteria. The seasonal or annual maximum series provide information on the frequency of extreme events which is not provided by either the seasonal-ambient or seasonal average series. From the maximum series a return period (frequency) can be associated with extreme events and used to evaluate risks of these events.

Summary

The annual-seasonal average series are not well represented due to the sampling frequency characteristics of the available water quality data. Extremes and single value measurements during a season impart bias to the desired representation. The best seasonal representation is provided by the seasonal-ambient data series. However, the seasonal-ambient data series does not provide information on frequency of specific events and only represents the percentage of

measurements less than a specified concentration. The seasonal or annual maximum series should be used with the seasonal-ambient series to provide frequency and risk information on extreme events.

CHAPTER 5
CRITERIA APPLICATIONS

Application of ambient water quality criteria for water quality management falls into two general categories: 1) assessing possible future changes in water quality, and 2) wasteload allocation for establishing permit discharges. The ambient water quality data are readily applicable to evaluating compliance of future water quality monitoring data with selected water quality criteria and is the focus of this chapter. Application of the water quality criteria to wasteload allocation and permit setting enters another realm of research. Wasteload allocation procedures are briefly discussed in context with the percentile water quality criteria.

Evaluating Changes In Water Quality

A primary objective of water quality management agencies is to monitor and evaluate future changes in water quality. Assessing future changes in water quality is necessary to evaluate the effectiveness and need for water quality controls on point and nonpoint discharges. Evaluating future water quality data is commonly thought of in terms of compliance with established criteria. The criteria proposed here are represented by percentiles.

As mentioned earlier, the 95th percentile concentration is often used to represent water quality based criteria. By monitoring the 95th percentile we control extreme exceedences of water quality. However, setting a 95th percentile criterion will not necessarily maintain the overall ambient water quality distribution. While maintaining extreme exceedences (i.e., 95th percentile), the average or median concentrations can increase or decrease significantly. In water quality management we are concerned with long-term average concentrations of total phosphorous and nitrogen as much, if not more so, than instantaneous extreme concentrations. Thus, the intermediate percentiles must also be considered to evaluate changes in average concentrations. The application presented here can be applied to any selected percentile or associated concentration level.

When the measured parameter concentration of a water quality sample is greater (or less for minimum concentration criteria) than an established criterion it is often referred to as an exceedence. The interpretation of this exceedence deals with determining whether it is a natural exceedence or due to changing water quality. Thus, exceedence of a water quality criterion does not mean a violation has occurred. Interpretation of future sampling data requires a statistical approach. Loftis and Ward (1981) and Ellis and Lacey (1980) both use the binomial distribution to define the expected number of exceedences in a given number of samples collected

over time. A typical instance might be for a monthly monitoring program where twelve samples are collected over one year, the objective is to determine the number of samples that might be expected to exceed a selected percentile concentration. Estimation of the expected number of exceedences must take into consideration two levels of confidence: 1) the confidence level associated with the percentile established as the criterion, and 2) the confidence level associated with the new water quality monitoring data. Each case represents a different random sample and the confidence level is based on the number of values in each sample.

Loftis and Ward (1981) used the confidence interval established for the estimated percentile as the same confidence interval for evaluating the new sampling data. In the example presented fifty-six measurements were used to estimate the ambient water quality percentile and confidence interval whereas, the random sample evaluated using the estimated percentile consisted of only twenty-four measurements. Clearly, the value of a selected percentile would not have the same confidence level in the two samples. For a specified 95^{th} percentile Ellis and Lacey (1980) determine maximum expected number of exceedences within a random sample based on the number of measurements but do not take into consideration the confidence level of the established percentile. The approach presented here takes

into consideration both levels of confidence which represent the total confidence level associated with a water quality management decision.

Detection of changes in water quality initially requires an ongoing water quality monitoring program. As new water quality data are obtained each new measurement can be evaluated individually and/or a series of data measurements can be evaluated as a group. Assuming a monthly sampling frequency, evaluation of future water quality data can be separated into two time frames: 1) evaluation of short-term water quality data consisting of from one measurement up to five years of data, and 2) evaluation of long-term water quality data (greater than five years of record).

Individual Data Measurements

Individual water quality measurements are evaluated simply by determining the ambient water quality percentile and deseasonalized water quality percentile for the measured concentration. For instance, specific conductance was measured at 280 umhos/cm at Fowlers Bluff on November 8, 1982. From Table 4-4, the ambient water quality percentile for a value of 280 umhos/cm at Fowlers Bluff is estimated to be 0.63. This means that 63 percent of the time the concentration is less than 280 umhos/cm, not considering seasonal variability. Because November is in the fourth quarter, which typically has higher specific conductance concentrations, the

deseasonalized percentile should also be examined. From Table 3-15 the mean and standard deviation for specific conductance during the fourth quarter at Fowlers Bluff are given as 281 umhos/cm and 68 umhos/cm, respectively. The deseasonalized concentration is calculated by subtracting the mean and dividing by the standard deviation as follows:

$$C_{ds}=\frac{280-281}{68}=-0.014$$

Entering Table 4-9 with the deseasonalized concentration, the percentile is approximately 0.47. This indicates that the measurement of 280 umhos/cm is less than the median (50^{th} percentile) when seasonal variability is taken into consideration. Thus, the initial ambient percentile provides a first check. If the ambient percentile is relatively high, the deseasonalized percentile can be evaluated which accounts for seasonal water quality changes.

When the estimated percentile for an individual measurement is above the 50^{th} percentile value, it does not necessarily indicate changing water quality. The percentiles are based on long-term data, therefore, variability about the median is expected over short time periods. An estimated percentile between 60 and 80 percent should be noted. If relatively high percentiles persist then further evaluation might be justified. If the percentile is extreme (>0.95), the situation might require investigation.

Multiple data measurements

A typical multiple data situation concerns the evaluation of a random sample made up of water quality measurements collected over a specified period of time (monitoring sample). For a monthly sampling frequency, the monitoring sample consists of twenty-four measurements over a period of two years. Evaluation of the monitoring sample must take into consideration the confidence level of the estimated percentile and the confidence level associated with the new random sample. Both confidence levels are established using the methodology presented in Chapter 4.

The percentile concentration being evaluated is used to determine the actual number of measurements from the monitoring sample that exceed the percentile concentration. For each water quality percentile concentration upper and lower bounds are established based on 1) selected percentile, 2) number of data measurements used to represent ambient water quality, and 3) desired level of significance. For a significance level of five percent we are ninety-five percent confident that the true value of the percentile of interest lies between the upper and lower bounds. The actual number of exceedences determined for the monitoring sample can vary depending on the specific concentration chosen to represent the percentile. Use of the upper bound represents a liberal choice in that the concentration representing the percentile is higher and the number of actual exceedences detected could

in turn be less. Alternatively, the lower bound represents a conservative choice and the number of actual exceedences detected would be expectedly higher. Lastly, the estimated value for the selected percentile represents a central concentration level between the two bounds.

The confidence limit for the monitoring sample establishes the maximum expected number of exceedences to be compared with the actual number of exceedences detected in the sample. The confidence level is calculated similarly to the percentile estimation except the confidence interval used is one sided and the maximum number of exceedences that might be expected is represented by the lower bound. For a significance level of α, equation (4-10) becomes

$$\sum_{i=0}^{L} \binom{n}{i} p^{i}(1-p)^{n-i} \leq \alpha \qquad 5\text{-}1$$

where p is the percentile level being evaluated, n is the number of measurements in the monitoring sample, and L represents the minimum number of measurements expected to be below the selected percentile concentration. The maximum number of measurements to exceed the percentile concentration becomes n - L. The maximum number of exceedences is then compared with the actual number of exceedences detected. This process is better visualized by example.

The methodology described above is applied to approximately two years of specific conductance measurements collected at Branford covering the time period September 1988

to January 1991. A step approach to evaluating the data is presented below.

Step 1. The first step consists of identifying the percentile levels to be evaluated. To represent extreme and average conditions the 50th and 95th percentiles are selected. The deseasonalized concentrations for the selected percentiles, upper bound and lower bound are obtained from Table 4-9 and shown in Table 5-1.

Table 5-1. Specific Conductance Deseasonalized Concentration for Selected Percentiles at Branford

95th Percentile		
Percentile Value		Deseasonalized Concentration (umhos/cm)
Estimated	0.95	1.28
Upper C.I.	0.967	1.30
Lower C.I.	0.926	1.21
50th Percentile		
Percentile Values		Deseasonalized Concentration (umhos/cm)
Estimated	0.50	0.16
Upper C.I.	0.547	0.02
Lower C.I.	0.452	0.33

Step 2. In the second step the seasonal statistics are obtained from Table 3-15 and used to deseasonalize the monitoring sample data. The deseasonalized concentrations are then compared with the percentile levels to determine the actual number of exceedences. Table 5-2 gives the seasonal

statistics for specific conductance at Branford and Table 5-3 gives the raw monitoring sample data, deseasonalized data and exceedences for each percentile level.

Table 5-2. Seasonal Statistics for Specific Conductance at Branford

Quarter	Mean (umhos/cm)	Standard Deviation (umhos/cm)
1	159	86.9
2	236	80
3	251	69.6
4	258	89.4

In Table 5-3 a zero indicates no exceedence and one indicates the measured concentration exceeds the deseasonalized percentile concentration. At the bottom of Table 5-3 the total number of detected exceedences are given for each percentile level.

Step 3. In this step the expected number of exceedences and maximum expected number of exceedences are calculated using equation 5-1 based on the number of observations in the monitoring sample. For relatively small sample sizes, several standard texts on statistics provide tables or figures for the cumulative Binomial distribution (Mendenhall et al., 1986; Miller and Freund, 1985). The desired significance level must be selected for determining the maximum expected number of exceedences. Three levels of significance are used for this

Table 5-3. Deseasonalized Concentrations and Exceedences in the Monitoring Sample for Selected Percentiles

Date	Measured Concentration	Deseasonalized Concentration	Detected Exceedences for Selected Percentiles					
			95th			50th		
			Expected	Upper	Lower	Expected	Upper	Lower
09/08/88	256	0.072	0	0	0	0	0	1
11/25/88	320	0.694	0	0	0	1	1	1
02/13/89	329	1.956	1	1	1	1	1	1
03/17/89	218	0.679	0	0	0	1	1	1
04/11/89	244	0.978	0	0	0	1	1	1
05/31/89	312	0.950	0	0	0	1	1	1
06/09/89	322	1.075	0	0	0	1	1	1
08/13/89	267	0.230	0	0	0	1	0	1
08/22/89	272	0.302	0	0	0	1	0	1
10/11/89	310	0.848	0	0	0	1	1	1
11/15/89	322	0.716	0	0	0	1	1	1
02/12/90	144	-0.173	0	0	0	0	0	0
03/12/90	142	-0.196	0	0	0	0	0	0
03/21/90	170	0.127	0	0	0	0	0	1
04/13/90	211	0.598	0	0	0	1	1	1
05/14/90	313	0.963	0	0	0	1	1	1
05/31/90	318	1.025	0	0	0	1	1	1
06/11/90	296	0.750	0	0	0	1	1	1
07/12/90	356	1.500	1	1	1	1	1	1
08/17/90	339	1.264	0	0	1	1	1	1
09/10/90	302	0.733	0	0	0	1	1	1
10/15/90	353	1.466	1	1	1	1	1	1
11/13/90	350	1.029	0	0	0	1	1	1
12/11/90	352	1.051	0	0	0	1	1	1
01/10/91	331	0.817	0	0	0	1	1	1
Total Actual Exceedances			3	3	4	21	19	23

example; 0.01, 0.025, and 0.05. The expected exceedences for each condition are given in Table 5-4.

Table 5-4. Expected Exceedences in Monitoring Sample for Selected Percentiles (n = 25)

Percentile Level	Number of Expected Exceedences	Maximum Number of Expected Exceedences		
		Significance Level		
		0.01	0.025	0.05
95th	1 to 2	5	6	6
50th	12 to 13	21	20	20

Step 4. For the last step the number of detected exceedences (Table 5-3) are compared with the expected number of exceedences (Table 5-4) and the results interpreted with respect to possible changes in water quality. For the 95th percentile, three exceedences of the expected concentration and upper confidence interval were detected and four exceedences of the lower confidence interval. Based on a monitoring sample of 25 observations, the number of expected exceedences are one to two and the maximum number of expected exceedences are five to six for the 95th percentile. The number of detected exceedences of the 95th percentile are just above the number of expected exceedences and below the maximum number of expected exceedences. For the 50th percentile, the number of detected exceedences are 21, 19 and 23 for the expected percentile concentration, upper confidence interval and lower confidence interval, respectively. While the number

of expected exceedences for the monitoring sample are 12 to 13 and the maximum number of expected exceedences are 20 to 21. These results tend to indicate that these measurements are above average but not extreme values. This evaluation compares with the results presented in Chapter 3 which indicated the most recent (1989-1990) specific conductance data to be generally higher at all the locations due to the significantly low flows during this period. The generally higher than average specific conductance concentrations should be noted. If this condition persists in more recent water quality monitoring data, further investigation would be warranted.

The application presented here can be applied to any of the three parameters and at any of the eight locations along the river. For a specific parameter, evaluation at all the locations can possibly identify where the source of possible water quality changes are occurring.

Long-term data

Comparison of long-term monitoring data to the ambient water quality data can be done using the Mann-Whitney test. Any of the trend analysis methods described in Chapter 3 can be used to evaluate long-term monitoring sample for detection of trends in water quality. A major consideration for detection of trends in water quality is having a sufficient data record for analysis. As previously stated the period of

record recommended for trend analysis is 10 years of continuous data. At a minimum five years of record is recommended. For comparison of data to the percentile distributions, a minimum of twenty measurements is necessary to represent a 95th percentile. This represents about two years of data collected on a monthly frequency.

Wasteload Allocation and Permitting

The objective of a wasteload allocation study is to establish the allowable pollutant concentration in the discharge from a point source. More recently the total maximum daily load (TMDL) process has been defined as the basis for States to establish water quality based controls (USEPA, 1991b). However, the TMDL process focuses entirely on water quality limited waters. Water quality limited waters are identified where water quality standards cannot be attained with the application of technology based standards. The TMDL process incorporates the loadings due to point sources (wasteload allocation), nonpoint sources (load allocations), and a safety factor based on the level of uncertainty for the problem being analyzed. Although this process was developed to bring limited water quality water bodies into compliance, it can be readily used to implement antidegradation water quality based standards. The TMDL basically consists of the sum of the component loads due to point sources and nonpoint sources. The development of the

TMDL involves use of already established techniques for wasteload allocation.

Various techniques are described in the literature for utilizing wasteload analysis to set permit discharges (USEPA, 1991a; Ambrose et al., 1988). Although the objective of wasteload analysis is estimation of pollutant loadings in the receiving water, the information required to represent the receiving water quality is in terms of concentration. EPA review of a methodology proposed by Oklahoma for implementing antidegradation policy pointed out that concentration is the primary focus versus a permitted load in the wasteload allocation process (USEPA, 1992). The information used to represent the receiving water quality varies from an average concentration to a distribution fitted to the water quality data.

Methods for assessing wasteload allocations focus on solving the general mass balance equation

$$C_x = \frac{Q_s C_s + q_e C_e}{Q_s + q_e} \quad , \qquad 5\text{-}2$$

where C_x = pollutant concentration downstream of point source discharge

Q_s = stream flow rate

C_s = instream pollutant concentration above point of discharge

q_e = point source discharge flow rate

c_e = pollutant concentration in point source discharge

The various techniques used to solve the general equation fall into four categories: 1) simple mass balance, 2) probabilistic dilution model, 3) Monte Carlo simulation, and 4) deterministic modeling. The simple mass balance approach assumes a steady state condition and selected critical design values are used as input for the parameters of the mass balance equation. Typically an average concentration is used to represent the upstream quality and a 7Q10 (average seven day low flow with a ten year return period) stream discharge. This combination is assumed to be conservative and provide protection of the receiving water quality. The disadvantage to the simplified approach is that the value of C_x is an undefined statistic and cannot be compared statistically with ambient water quality. Any of the estimated percentile concentrations can be used in this equation.

The second approach assumes that all the parameters in the mass balance equation are lognormally distributed and independent. Di Toro (1984) and Warn and Brew (1980) have developed analytical solutions for this approach. Application of the water quality data to this approach would simply require estimating the parameters for the lognormal distribution based ambient water quality data.

The third technique uses a Monte Carlo simulation model. The variables in the equation can be represented by best fit

probability distributions (not necessarily lognormal), sampled from the historical data set, or represented by a time series. The Monte Carlo approach provides the most flexibility for representing the ambient water quality data.

The fourth approach uses a continuous simulation model. This approach requires the most effort and information of any of the methods. The ambient water quality data can be used to calibrate and verify the model or used directly as input to the model.

All three later methods provide a statistical solution that can be compared with the ambient water quality data to assess changes in water quality. Receiving water quality in all the methods is represented in terms of concentration and the ambient water quality data thus provide the information necessary to use any of these methods.

Summary

Numerical representation of ambient water quality for specific conductance, total phosphorus, and total nitrogen has been developed for eight locations along the Suwannee River. The numerical representation is in the form of percentiles which provides a statistical depiction of the ambient water quality variability. Variability has also been represented by seasonal characteristics on a quarterly basis.

Application of the ambient water quality percentiles has been presented for evaluation of future water quality

measurements. Confidence limits on the estimated percentiles have been established for each parameter at each location based on the ambient water quality data. The confidence interval used to estimate the maximum number of measurements expected to exceed a selected percentile is established based on the monitoring sample. Both levels of confidence are used to evaluate and interpret the monitoring sample for changes in water quality. The results of the application must be interpreted taking into consideration all available information including the length of record used for developing the percentiles, and with respect to what is occurring at other locations along the River.

A systematic approach to evaluating future water quality measurements might consist of the following steps:

1. evaluate individual measurements as they are made,

2. evaluate the water quality data collected each year as a multiple data set,

3. evaluate the cumulative data set to date as a multiple data set, and

4. when, data are available for five or more years conduct a medians analysis with the ambient water quality data and a trend analysis on the five-year monitoring sample.

After the data gathered over a five-to-ten year period can be shown to have no significant water quality impacts, the data can be combined with the original ambient water quality data set allowing new percentiles and confidence intervals to be calculated following the methods described in this study.

CHAPTER 6
SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

Summary

Implementation of antidegradation water quality standards requires that ambient water quality be defined based on the "best scientific information available." Strict adherence to statistical assumptions can eliminate much of the available data from consideration. To obtain enough data for the analysis will often require combining data sets collected by several different agencies. Combining data from different agencies is often questioned due to variability caused by differences in sampling frequency, sampling time period, and analytical variability. Total phosphorus data sets at the same locations did not compare well statistically. However, these differences appear to be masked by the natural variability of total phosphorus water quality. The effect of variability between data sets was evaluated by comparing the single 112WRD data set at Branford with results of the combined data sets at the Branford location. The difference between percentile distributions for the two data sets is only apparent at very low concentrations. This reflects the difficulty in analytical measurement of low phosphorus concentrations. At higher concentrations the analytical

variability is reduced. Thus, the concerns often expressed regarding differences in lab techniques, sampling, etc. do not necessarily represent significant differences in the end result.

The data analysis protocol (DAP) provides a consistent approach to statistical analysis and interpretation of historical water quality data for defining ambient water quality. Interpretation of the statistical analysis and development of ambient water quality criteria were benefitted by evaluating the results at several locations along the river. Trends indicated at downstream locations could be interpreted with knowledge of conditions upstream. Multiple analysis was especially beneficial at locations with limited data and long periods of missing data. Additionally, uniformity of results along the river provides support for establishing ambient criteria. Development of ambient water quality criteria should be conducted uniformly basin wide. More important for the Suwannee River basin is consideration of water quality management practices in Georgia, where over half the drainage basin lies. Comprehensive water quality management within the Suwannee River will require coordination with appropriate State agencies in Georgia.

Several agencies, both State and Federal, have been involved with water quality monitoring along the Suwannee River at various time periods. Detection of changes in water quality and evaluation of water quality management controls

will require consistent long term monitoring. Water quality monitoring by any one agency is often controlled by available funding. It would seem logical and economically efficient to combine efforts and resources of interested agencies to formulate a single consistent monitoring program that can be maintained on a long term basis.

The ambient water quality is represented statistically in terms of percentiles based on the complete data set. These percentiles only represent the number of measurements that are less than a specified concentration level. The concept of criterion event definition, which incorporates magnitude, duration and frequency into water quality criteria was evaluated. The primary component for establishing event based criteria is duration (averaging period). Sampling frequency controls the duration that can be used. For the Suwannee River, water quality percentiles based on a quarterly averaging period did not provide any better representation of ambient water quality than the complete data set due to the variability and relatively low sampling frequency of the available data. However, the annual maximum series does provide added information for interpretation and frequency of extreme events.

Use of the ambient water quality representation developed in this research is provided for in the current antidegradation water quality standards. Full implementation of antidegradation standards in other States (Nevada, Hawaii,

Arizona) has only been achieved by adopting the ambient criteria into State regulations. It appears that the proposed criteria might not be fully accepted or implemented unless they are officially adopted through State regulations.

Application of the ambient criteria developed herein requires a clear understanding and representation of the variability associated with different estimated values. Through this research a procedure has been presented that recognizes both variability within the estimated percentile criterion and variability within the water quality monitoring sample being evaluated.

Conclusions

Development of water quality criteria for implementing antidegradation water quality standards requires there primary tasks: 1) gathering and assemble available water quality data into a coherent data base, 2) statistical analysis for representing ambient conditions, and 3) establishing criteria that reflect the natural variability of ambient water quality. The work presented herein follows a formalized approach to establishing ambient water quality criteria. General conclusions regarding the establishment of ambient criteria are:

1. Definition of ambient water quality is the fundamental element for establishing antidegradation water quality criteria.

2. The data analysis necessary to define ambient water quality provides a definitive representation of water quality characteristics for informed water quality management.
3. A basinwide approach to analysis and definition of ambient water quality provides a temporal and spatial representation enhancing the interpretation and application of the defined criteria.
4. Combined efforts of interested agencies to establishing a sustained long-term monitoring program would seem logical and economically efficient.
5. Application of the criterion event definition concept is limited by the variability and frequency of sampling. Infrequent sampling results in biased averages that are highly variable making water quality management decisions unreliable.
6. Annual seasonal maximums and annual maximums provide a better representation of extreme concentrations that are not necessarily apparent in the ambient percentile representation and provide for risk assessment of exceeding extreme events.
7. Application of the developed ambient criteria requires a clear understanding of the statistical methods and confidence levels for estimated percentiles. Evaluation of future water quality data requires consideration of

percentile confidence intervals for both the ambient water quality data and the monitoring water quality data.

8. Although antidegradation standards provide for use of the established criteria, full implementation may require adoption through State regulations.

Future Research

Based on the work presented herein three general recommendations for future research are:

1. Development of simulation techniques for application to wasteload allocation, TMDL process and deterministic modeling.

The TMDL process uses a water quality based approach to establish wasteload allocations for point sources and load allocations for nonpoint sources. Application of the ambient water quality based criteria through the TMDL process provides a mechanism for implementing antidegradation criteria.

Assessment of future changes in land use, nonpoint source impacts, point source impacts, and effectiveness of water quality control alternatives requires some level of deterministic modeling. Combining deterministic modeling with statistical ambient water quality representation can provide a realistic representation of the natural system. An important consideration associated with deterministic modeling is evaluation of ecological system response to changes in water quality.

2. Evaluation and statistical representation of multiparameter criteria such as metals that are a function of pH and hardness.

Recently, metals criteria have been adopted that depend on hardness. Additionally, metals equilibrium depends highly on pH. Dissolved metal concentrations within the system is highly dependent on chemical equilibrium relationships. Research into the statistical representation of equilibrium conditions within the river system will provide necessary information for assessment of ambient metal concentrations in the system and for evaluation of changes in water quality.

3. Refined definition of ecological response concentration levels are necessary to define "significant degradation."

Although ambient water quality has been established, the level of water quality change that represents significant degradation remains to be defined. Definition of significant degradation is linked to ecological responses to changes in water quality. Information regarding threshold response levels of ecosystems to changes in water quality in a riverine environment is necessary to define significant degradation. Establishing ambient conditions provides a means to quantify changes in water quality. Subsequently, changes in water quality must be reformulated into an evaluation of ecosystem response. Therefore, the response of the riverine ecosystem to changes in water quality needs to be defined. These

responses can be based on historical data or by comparison of ecosystem stages between impacted and unimpacted river systems or possibly through deterministic modeling approaches.

APPENDIX
STATISTICAL PROCEDURES

Mann-Whitney Test

The Mann-Whitney test is used to assess differences in central tendency between two random samples $X_1,...X_m$ and $Y_1,...Y_n$ where it is assumed that both samples come from continuous populations. The basic hypothesis is that no difference exists:

$$H_o: \Delta = 0 \qquad \text{A-1}$$

The two random samples X_i and Y_j are combined into a single sequence of m+n = N variables and ranked from the least to the greatest. The Mann-Whitney U statistic is

$$U = mn + \frac{m}{2}(m + 1) - R_1 \qquad \text{A-2}$$

or

$$U' = mn + \frac{n}{2}(n + 1) - R_2 \ , \qquad \text{A-3}$$

where

R_1 = the sum of the ranks assigned to the m X_i values, and

R_2 = the sum of the ranks assigned to the n Y_j values.

As a check on accuracy of calculations,

$$R_1 + R_2 = \frac{N}{2}(1 + N) . \qquad \text{A-4}$$

For a two-sided test of H_o (A-1) versus the alternative $\Delta \neq 0$, at the α level of significance, reject H_o if

$$U \geq U(\text{upper},\alpha,m,n) \text{ or } U \leq U(\text{lower},\alpha,m,n).$$

For m and n less than or equal to twenty U(upper,α,m,n) and U(lower,α,m,n) are tabularized in several standard statistical texts (Runyan, 1977). For m and n both larger than twenty the test statistic can be approximated as

$$Z = \frac{U - \frac{mn}{2}}{\sqrt{\frac{1}{12}[mn(m+n+1)]}} . \qquad \text{A-5}$$

When tied observations occur between the two samples a correction is required where:

$$T = \frac{1}{12}(t^3 - t) , \qquad \text{A-6}$$

and t is the number of tied observations for a given rank. The corrected test statistic is

$$Z = \frac{U - \frac{mn}{2}}{\sqrt{\frac{mn}{N(N+1)}\left(\frac{N^3-N}{12} - \sum T\right)}} , \qquad \text{A-7}$$

where $\sum$ T is the sum of T's over all groups of tied observations. For a two-sided test of H_o (A-1) versus the alternative $\Delta \neq 0$, at the α level of significance,

$$|Z| \geq Z_{\frac{\alpha}{2}} ,$$

where $Z_{\alpha/2}$ is the standard normal variate.

Kruskal-Wallis Test

The Kruskal-Wallis test is an extension of the Mann-Whitney test to more than 2 random samples (e.g. multiple seasons). The basic hypothesis is that the k samples can be thought of as a single (combined) sample from one population. The data are represented as

$$N = \sum_{j=1}^{k} n_j \qquad \text{A-9}$$

observations, with n_j observations from the jth season, j=1,...k.

The null hypothesis is tested by first combining the N observations into a single ordered sequence and ranking the observations from smallest to largest. Let r_{ij} denote the rank of X_{ij} in this joint ranking. The sum of the ranks for each sample, R_j, is computed

$$R_j = \sum_{i=1}^{n_j} r_j \ . \qquad \text{A-10}$$

Subsequently, the average rank for sample j is

$$\bar{R}_j = \frac{R_j}{n_j} \quad . \qquad \text{A-11}$$

The test criterion is a weighted sum of squares of deviations, with the reciprocals of the respective sample sizes used as weights. The Kruskal-Wallis test statistic H is defined as

$$\begin{aligned} H &= \frac{12}{N(N+1)} \sum_{j=1}^{k} n_j \left(\bar{R}_j - \frac{(N+1)}{2}\right)^2 \\ &= \left(\frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j}\right) - 3(N+1) \quad . \end{aligned} \qquad \text{A-12}$$

When ties occur across samples the test H is corrected by

$$H' = \frac{H}{1 - \left(\dfrac{\sum_{j=1}^{g} T_j}{(N^3-N)}\right)} \quad , \qquad \text{A-13}$$

where g = number of tied groups and $T_j = (t_j^3 - t_j)$, with t_j the number of tied observations at rank j. When ties exist H' is substituted for H to test the hypothesis.

The null hypothesis is rejected for large values of H at a significance level of α accordingly

reject H_o if $H \geq h(\alpha, k, (n_1, \ldots, n_k))$,

where $P\{H \geq h(\alpha, k, (n_1, \ldots, n_k))\} = \alpha$. Values of $h(\alpha, k, (n_1, \ldots, n_k))$ are tabularized in many standard statistics texts (Gibbons, 1971; Hollander and Wolfe, 1973).

For all $n_j > 5$, H is distributed as chi-square with k-1 degrees of freedom and the test on the null hypothesis becomes

reject H_o if $H \geq \chi^2_{(k-i,\alpha)}$.

The chi-square statistic, $\chi^2_{(k-i,\alpha)}$, is tabularized in many standard statistics texts (Gibbons, 1971; Hollander and Wolfe, 1973).

Seasonal Kendall Test
(Hirsch and Slack, 1982; Hirsch et al., 1984)

The seasonal Kendall test for trend is a modification of Kendall's tau which is insensitive to the existence of seasonality. The null hypothesis H_o is that the observations are randomly ordered within each season versus the alternative of monotone trend in one or more seasons over time. Let the matrix

$$X = \begin{pmatrix} X_{11} & X_{12} & \cdots & X_{1p} \\ X_{21} & X_{22} & \cdots & X_{2p} \\ \cdot & \cdot & & \cdot \\ X_{n1} & X_{n2} & \cdots & X_{np} \end{pmatrix} \qquad \text{A-14}$$

denote a sequence of observations taken over p seasons for n years. Let the matrix

$$R = \begin{pmatrix} R_{11} & R_{12} & \cdots & R_{1p} \\ R_{21} & R_{22} & \cdots & R_{2p} \\ \cdot & \cdot & & \cdot \\ R_{n1} & R_{n2} & \cdots & R_{np} \end{pmatrix} \qquad \text{A-15}$$

be the matrix of ranks corresponding the observations in X, where the ranks are determined within each season for n observations. The Kendall test statistic for each season is

$$S_g = \sum_{i<j}^{n} sgn(X_{jg} - X_{ig}) \qquad g = 1,2,\ldots,p \qquad \text{A-16}$$

where

$$sgn\ (\theta) = \begin{cases} 1 & if\ \theta > 0 \\ 0 & if\ \theta = 0 \\ -1 & if\ \theta < 0 \end{cases} \qquad \text{A-17}$$

The Seasonal Kendall test statistic is

$$S' = \sum_{g=1}^{p} S_g \ . \qquad \text{A-18}$$

The seasonal Kendall test statistic is asymptotically normal with mean 0 and variance

$$var\ [S'] = \sum_{g=1}^{p} var[S_g] + \sum_{g,h;g\neq h}^{p} cov\ (S_g,\ S_h) \ . \qquad \text{A-19}$$

For independent random variables cov (S_g, S_h) = 0 and

$$var\ [S'] = \sum_{g=1}^{p} \frac{n_g(n_g - 1)\,(2n_g + 5) - \sum_{t_i}^{m} t_i(t_i - 1)\,(2t_i + 5)}{18}$$

A-20

where m is the number of tied groups among the $X_{1,g}$ and t_j is the size of the j^{th} tied group. The test statistic is converted to a standard normal with a continuity correction of one unit made toward zero. The continuity correction accounts for the fact that S' may only take on even values. The standard normal deviate Z' is defined as

$$Z' = \begin{cases} \dfrac{S' - 1}{(var\ (S'))^{1/2}} & if\ S' > 0 \\ 0 & if\ S' = 0 \\ \dfrac{S' + 1}{(var\ (S'))^{1/2}} & if\ S' < 0 \end{cases} \qquad \text{A-21}$$

Z' is compared with the standard normal variate $Z_{\alpha/2}$.

To account for dependence within the data $\sigma_{gh} = cov(S_g, S_h)$ is estimated as

$$\hat{\sigma}_{gh} = \frac{K_{gh}}{3} + \frac{(n^3 - n)\, r_{gh}}{9} \qquad \text{A-22}$$

where

$$K_{gh} = \sum_{i<j}^{n} sgn[(X_{jg} - X_{ig})(X_{jh} - X_{ih})] \qquad \text{A-23}$$

and

$$r_{gh} = \frac{3}{n^3 - n} \sum_{i,j,k}^{n} sgn\ (X_{jg} - X_{ig})\ (X_{jh} - X_{kh}) \qquad \text{A-24}$$

The estimates for σ_{gh} are used in the calculation of the variance of S' only for n ≥ 10. For n < 10 equation A-20 is used.

SEASONAL KENDALL SLOPE ESTIMATE
(Hirsch and Slack, 1982)

Compute the individual slope estimates between sequential pairs of observations

$$d_{ijk} = \frac{(x_{ij} - x_{ik})}{(j - k)} \qquad \text{A-25}$$

for all (x_{ij}, x_{ik}) pairs

$i = 1,2,....,p$

$1 \leq k < j \leq n_i$

p = number of seasons

n_i = number of observations in season i

The Seasonal Kendall Slope Estimate B, is defined as the medium value of the individual slopes d_{ijk}. B is related to the Seasonal Kendall test statistic S, accordingly

if S' > 0, B ≥ 0 (B > 0 if one or no $d_{ijk} = 0$)

if S' < 0, B ≤ 0 (B < 0 if one or no $d_{ijk} = 0$).

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BIOGRAPHICAL SKETCH

Scott J. Kenner was born and raised in Rapid City, South Dakota. His love for the outdoors and fishing led him to pursue a degree in civil engineering with emphasis in environmental engineering. He received his bachelor's and master's in civil engineering from the South Dakota School of Mines and Technology (SDSM&T) in 1977 and 1979, respectively. While completing his formal education he married Mary Ann Taggart in October of 1976.

He started his professional engineering career in Denver, Colorado, where he worked for five years before moving to Cheyenne, Wyoming. After two years in Wyoming he returned to Rapid City in 1984 to work for a local engineering consulting firm. In 1986 he was selected as Outstanding Young Engineer of the Year by the South Dakota Society of Professional Engineers. In 1988 he was recognized as an Outstanding Recent Graduate in Civil Engineering by SDSM&T.

While in Rapid City he had the opportunity to teach as an adjunct professor at SDSM&T. This opportunity led him to return to school to obtain his Ph.D. at the University of Florida where he will become an Assistant Professor in the Department of Environmental Engineering Sciences starting August, 1992.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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